11-2013

CE-QUAL-W2 Model and Model Set-Up

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Citation Details

Wells, S. A. (2013) "CE-QUAL-W2 Model and Model Set-Up," EPA Region 6 Water Quality Workshop and Conference, Dallas TX, November 2013.

CE-QUAL-W2

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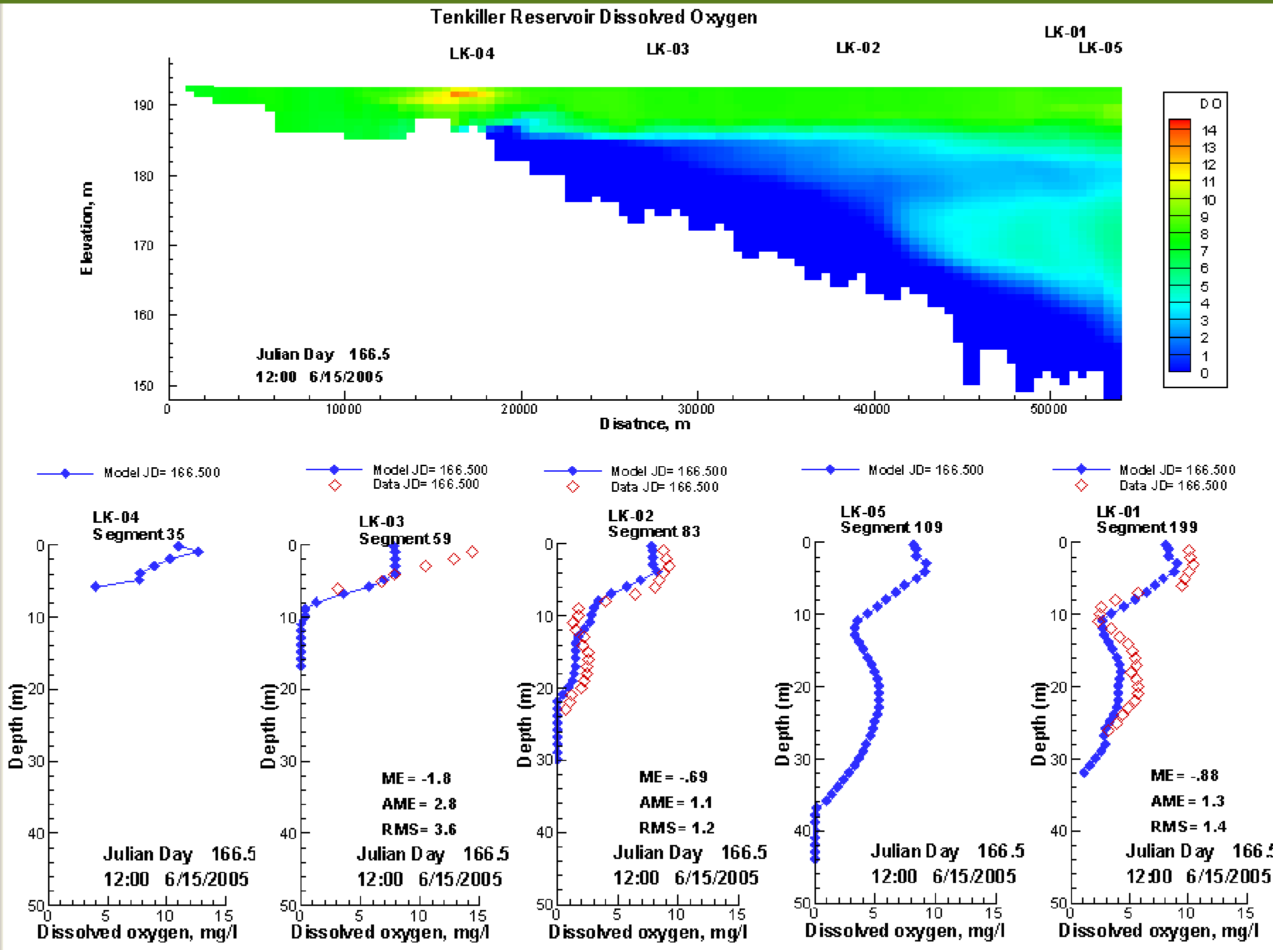

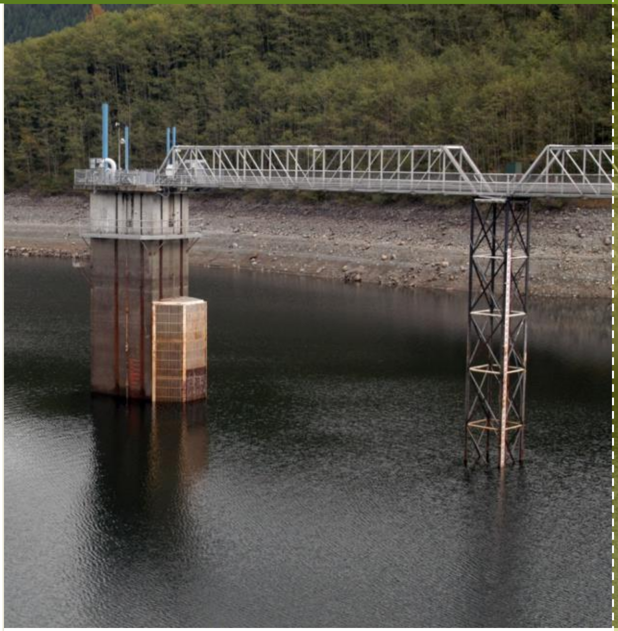

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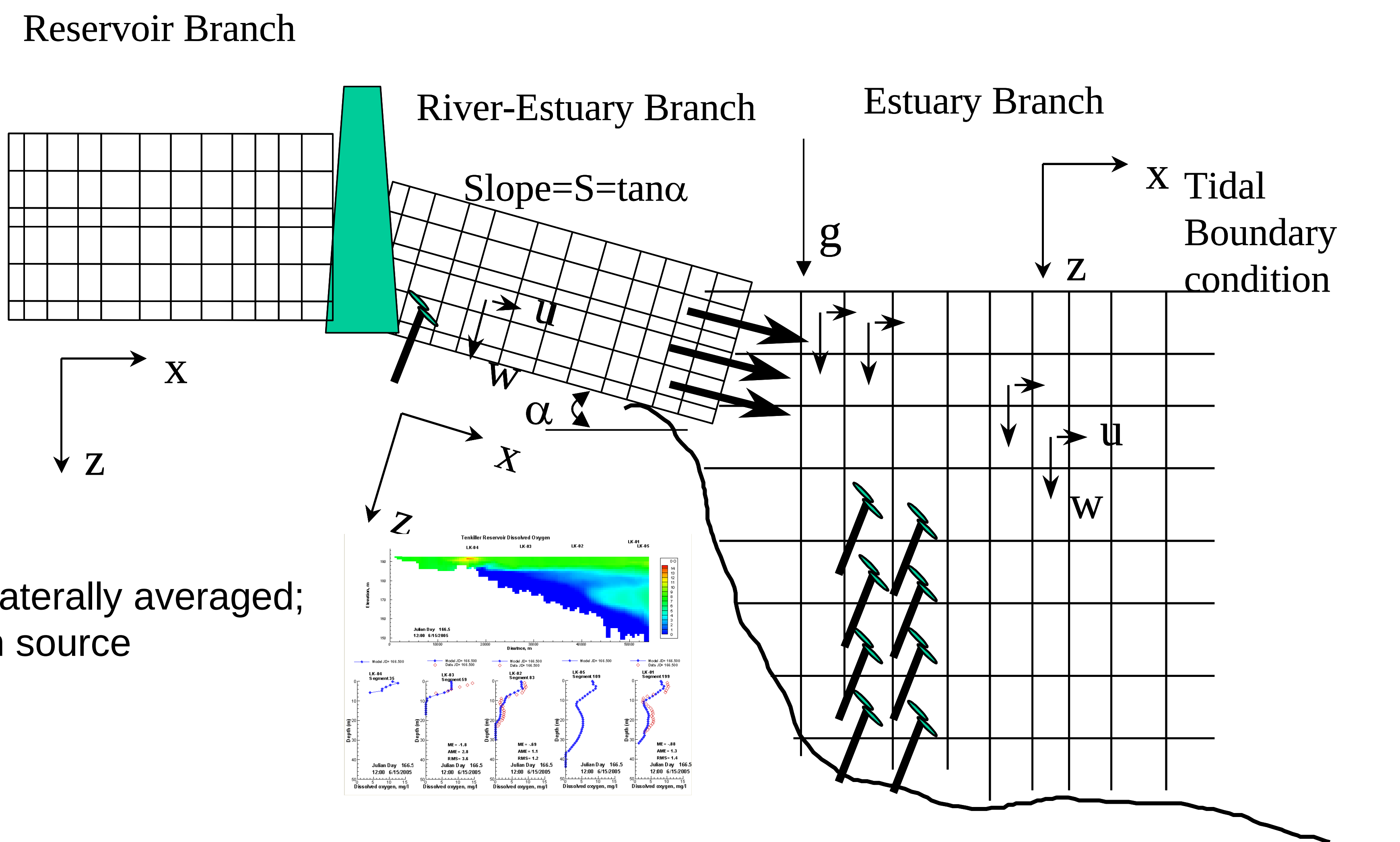
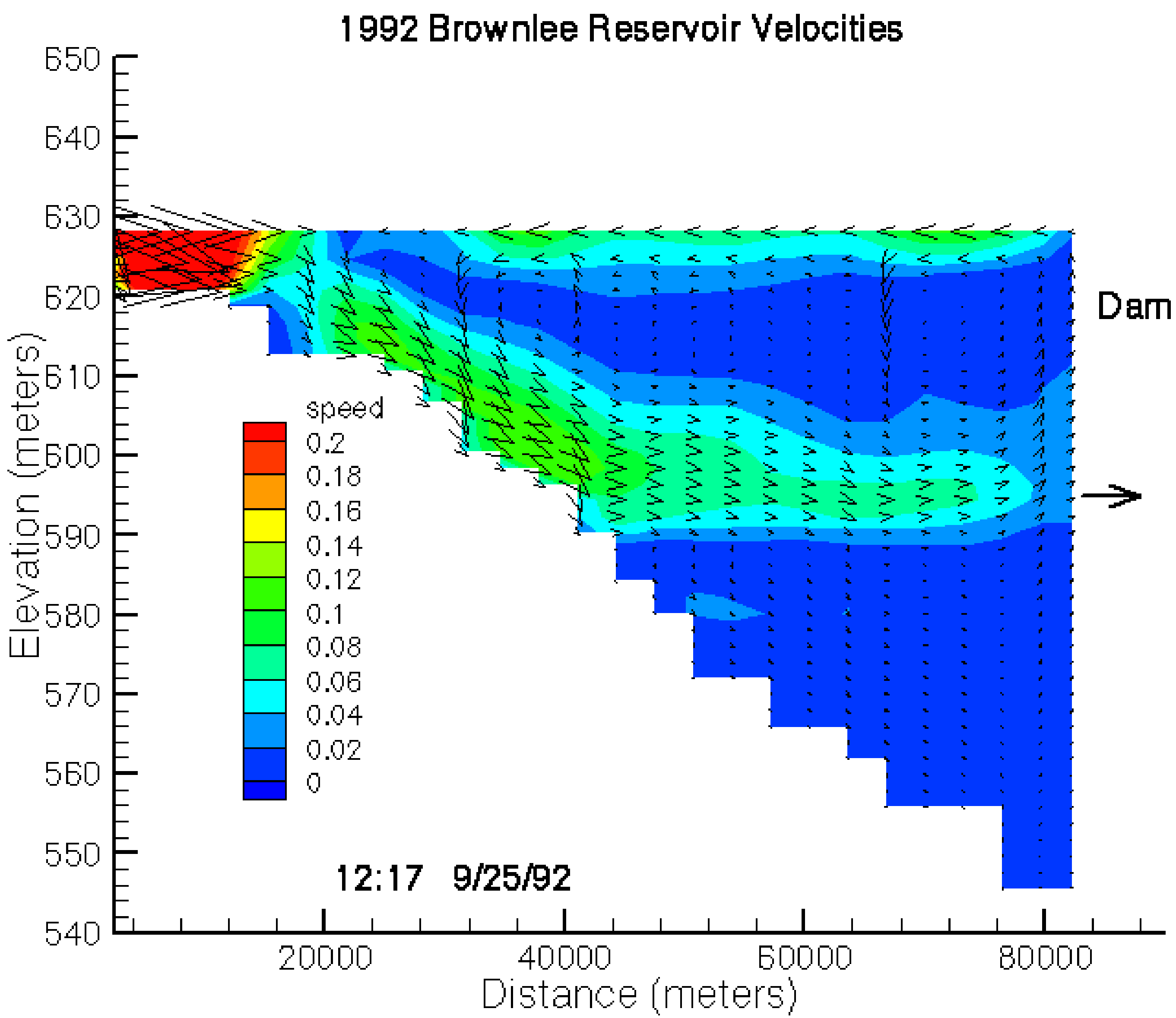
CE-QUAL-W2

- Background of CE-QUAL-W2
  - Governing equations and limitations
  - Model state and derived variables
- Example application
- How to set-up and run CE-QUAL-W2
- CE-QUAL-W2 planned enhancements

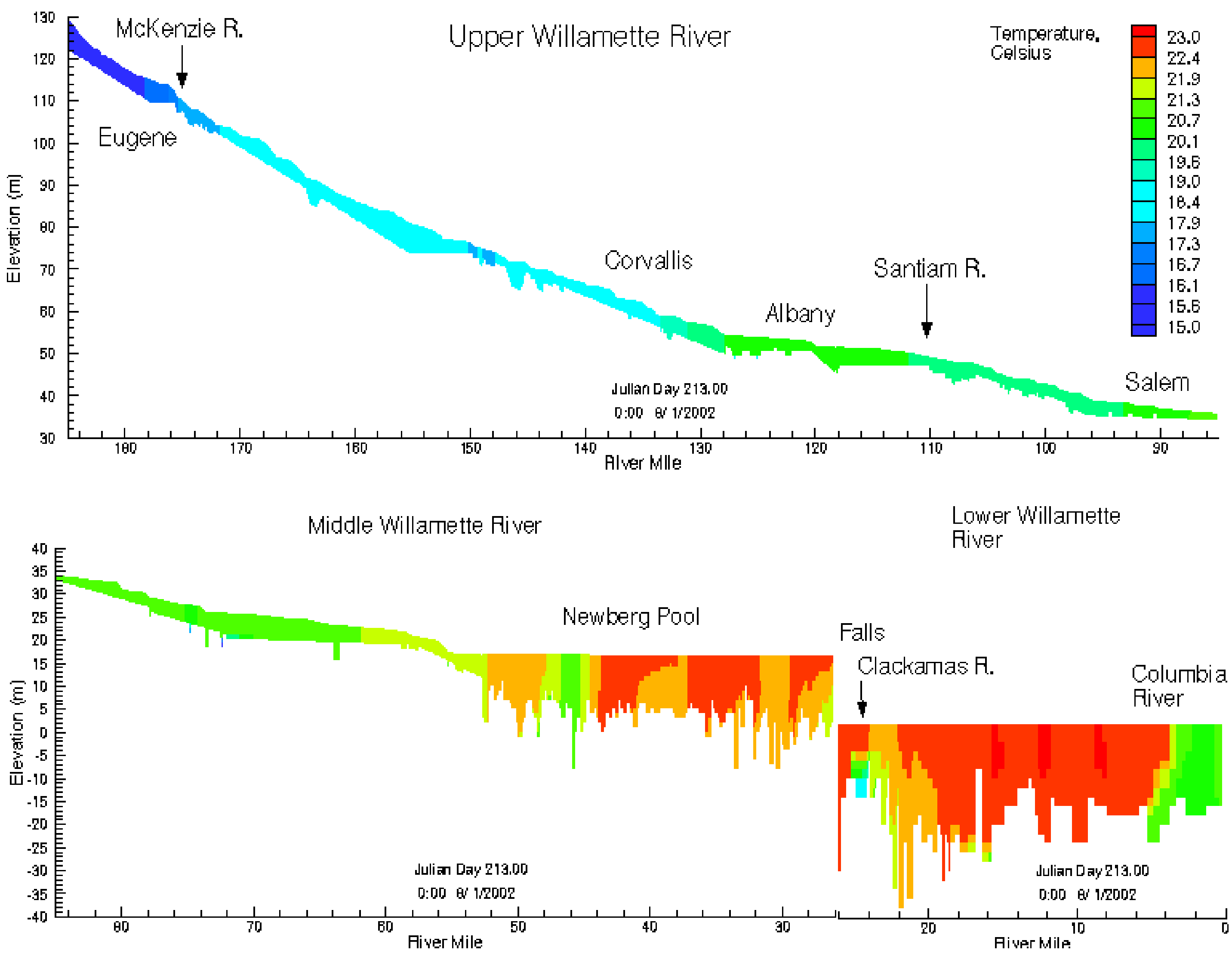
CE-QUAL-W2



2D, laterally averaged; open source


1992 Brownlee Reservoir Velocities
Elevation (meters)
650
640
630
620
610
600
590
580
570
560
550
540
Distance (meters)
20000
40000
60000
80000
speed
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Dam
12:17 9/25/92

River Modeling – Estuary Modeling



CE-QUAL-W2 Governing Equations

Equation	Version 3 governing equations
x- momentum	$\frac{\partial UB}{\partial t}+\frac{\partial UUB}{\partial x}+\frac{\partial WUB}{\partial z}=gB\sin\alpha+g\cos\alpha B\frac{\partial\eta}{\partial x}-\frac{g\cos\alpha B}{\rho}\int_{\eta}^{z}\frac{\partial\rho}{\partial x}dz+\frac{1}{\rho}\frac{\partial B\tau_{xx}}{\partial x}+\frac{1}{\rho}\frac{\partial B\tau_{xz}}{\partial z}+qBU_x$
z-momentum	$0=g\cos\alpha-\frac{1}{\rho}\frac{\partial P}{\partial z}$
free surface equation	$B_\eta\frac{\partial\eta}{\partial t}=\frac{\partial}{\partial x}\int_{\eta}^{h}UBdz-\int_{\eta}^{h}qBdz$
continuity	$\frac{\partial UB}{\partial x}+\frac{\partial WB}{\partial z}=qB$
equation of state	$\rho=f(T_w,\Phi_{TDS},\Phi_{ss})$
Conservation of mass/heat	$\frac{\partial B\Phi}{\partial t}+\frac{\partial UB\Phi}{\partial x}+\frac{\partial WB\Phi}{\partial z}-\frac{\partial\left(BD_x\frac{\partial\Phi}{\partial x}\right)}{\partial x}-\frac{\partial\left(BD_z\frac{\partial\Phi}{\partial z}\right)}{\partial z}=q_\Phi B+S_\Phi B$

Algorithms for τ_{xz} : Several different algorithms available

k-ε Turbulence Model

Use 'TKE' as the designator for the turbulence model

$$\nu_t = C_\mu \frac{k^2}{\varepsilon}$$

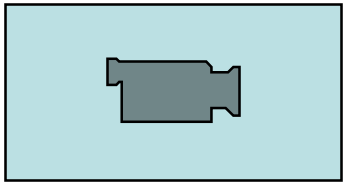
k-ε Turbulence Model

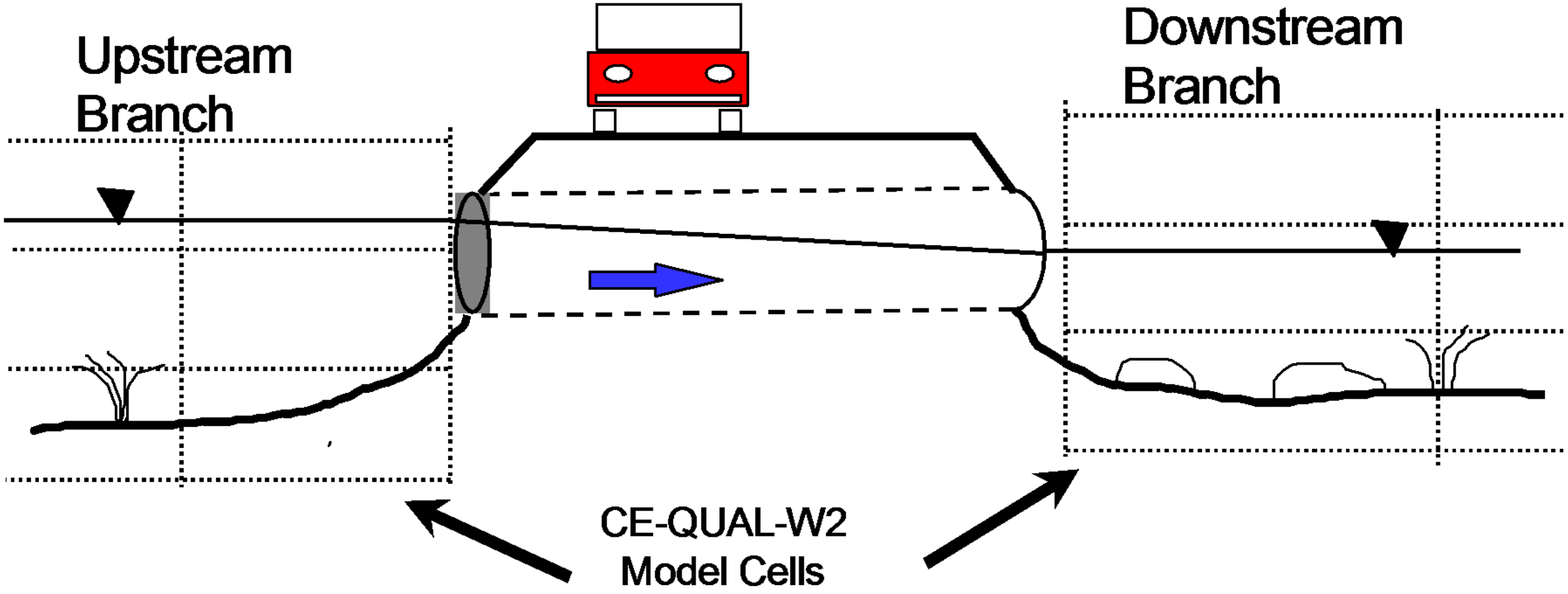
This involves the solution of the following PDEs

$$\frac{\partial kB}{\partial t} + \frac{\partial kBU}{\partial x} + \frac{\partial kBW}{\partial z} - \frac{\partial}{\partial z}\left(B\frac{\nu_t}{\sigma_k}\frac{\partial k}{\partial z} \right) - \frac{\partial}{\partial x}\left(B\frac{\nu_t}{\sigma_k}\frac{\partial k}{\partial x} \right) = B\left(P + G - \varepsilon + P_k\right)$$

$$\frac{\partial \varepsilon B}{\partial t} + \frac{\partial \varepsilon BU}{\partial x} + \frac{\partial \varepsilon BW}{\partial z} - \frac{\partial}{\partial z}\left(B\frac{\nu_t}{\sigma_\varepsilon}\frac{\partial \varepsilon}{\partial z} \right) - \frac{\partial}{\partial x}\left(B\frac{\nu_t}{\sigma_\varepsilon}\frac{\partial \varepsilon}{\partial x} \right) = B\left(C_{\varepsilon 1}\frac{\varepsilon}{k}P + C_{\varepsilon 2}\frac{\varepsilon^2}{k} + P_\varepsilon \right)$$

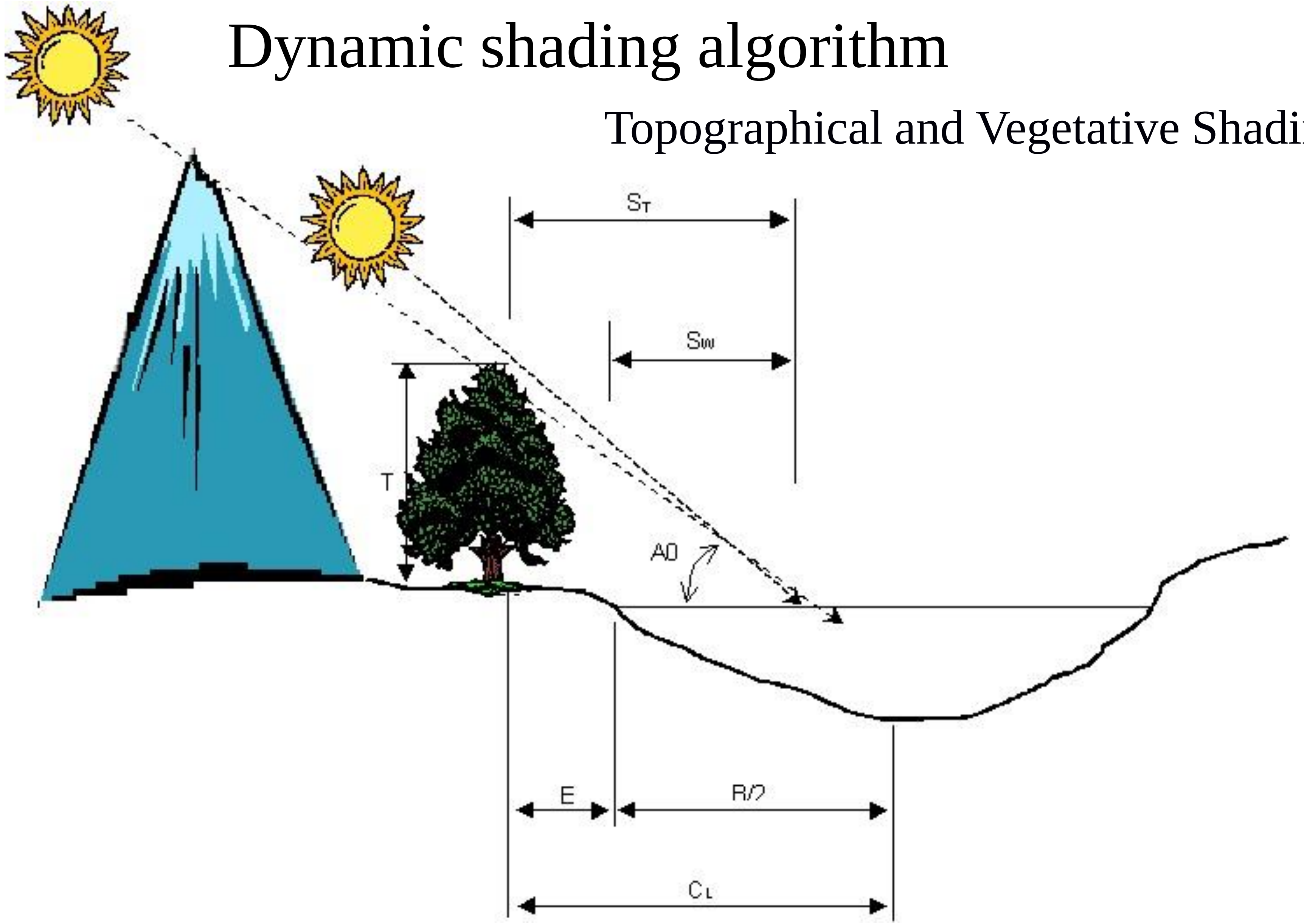
Internal Hydraulic Structures



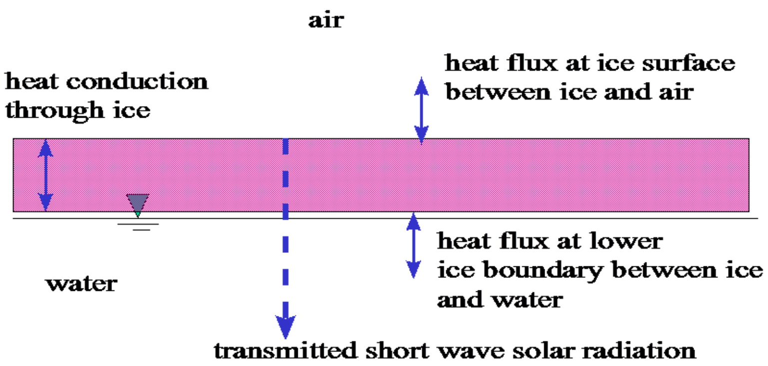


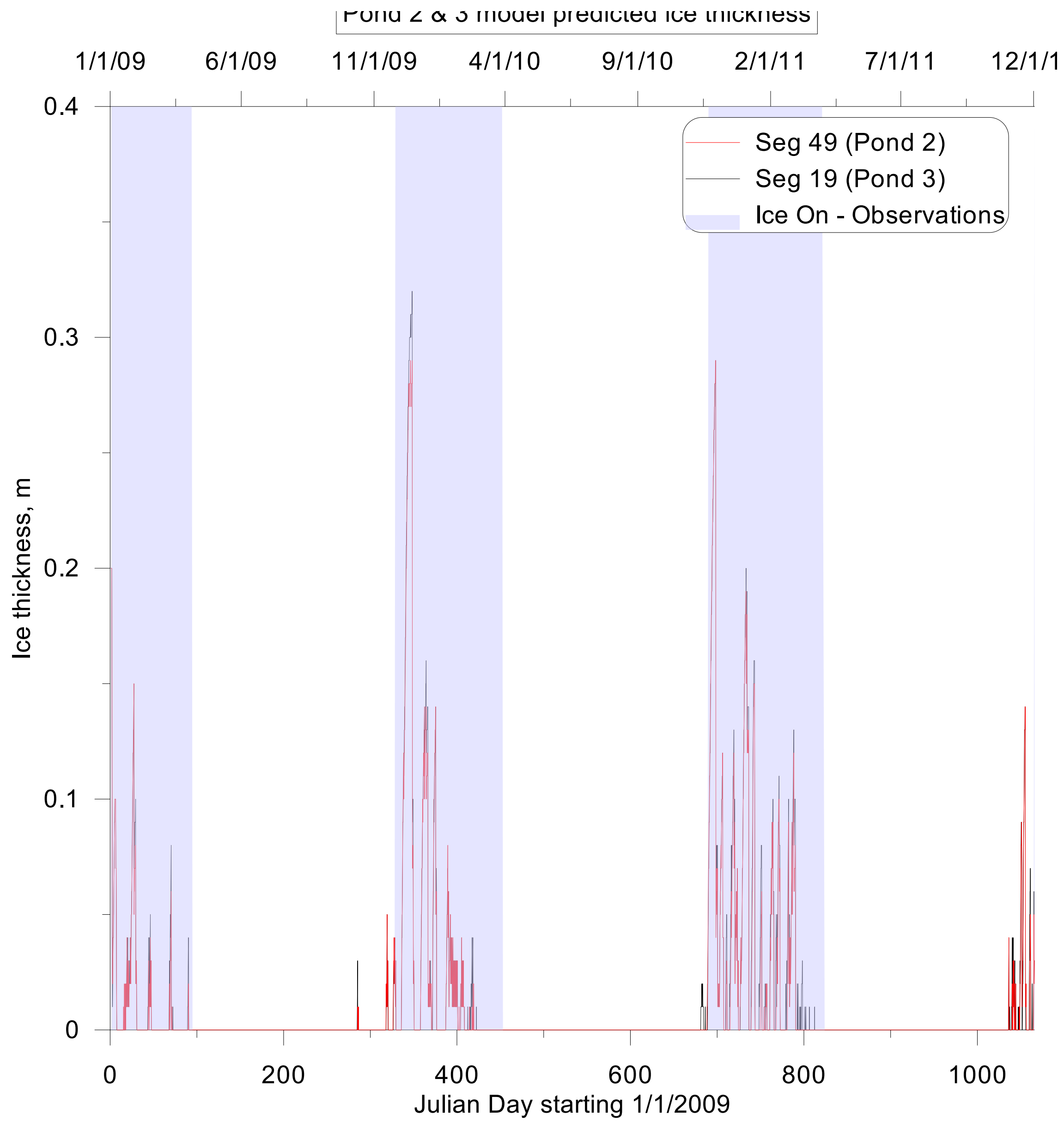
Dynamic shading algorithm

Topographical and Vegetative Shading



Model predictions of ice cover

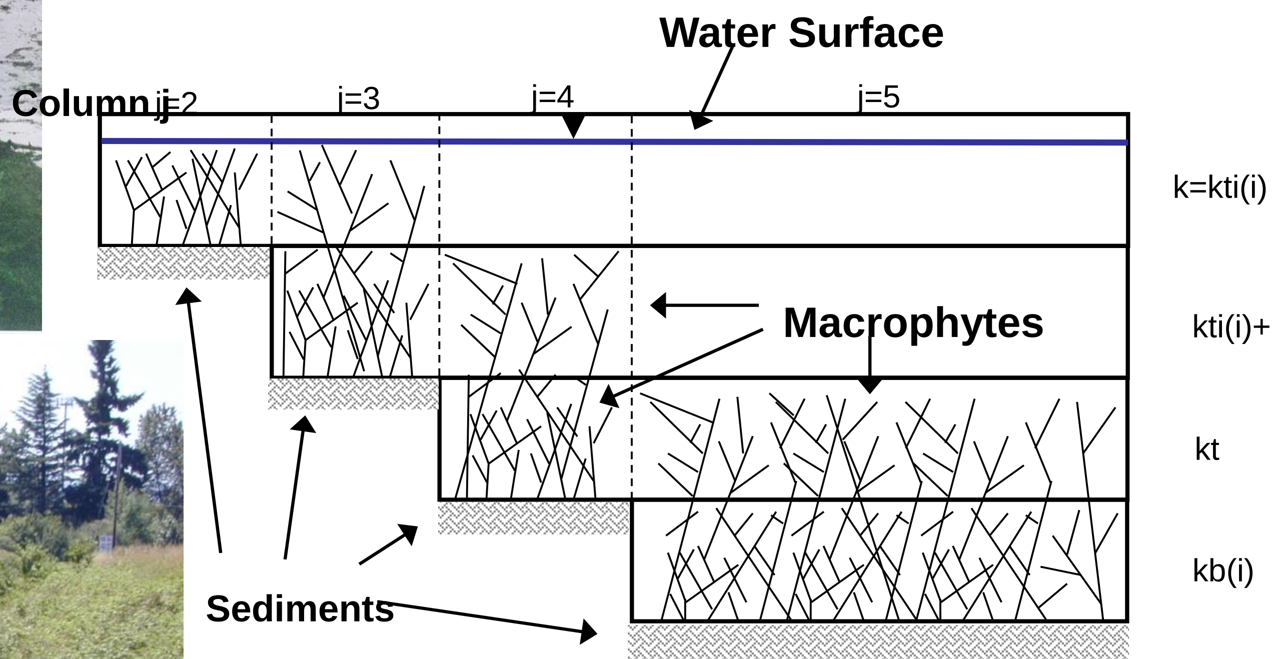


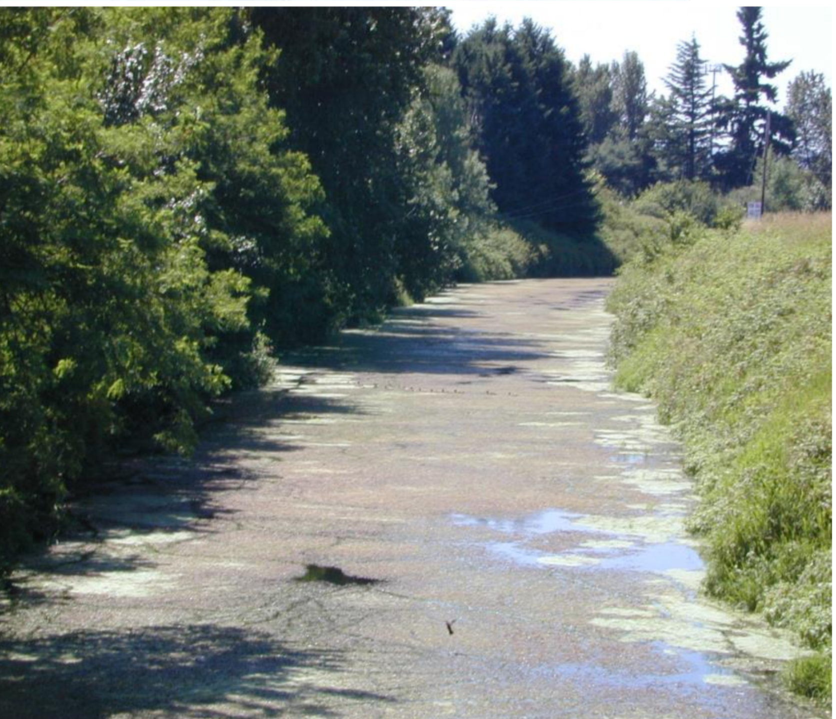


Water quality state variables

- any number of generic constituents:
  - conservative tracer(s)
  - water age or hydraulic residence time
  - coliform bacteria(s)
  - contaminant(s)
- any number of inorganic suspended solids groups
- any number of phytoplankton groups
- any number of epiphyton/periphyton groups
- any number of CBOD groups
- any number of zooplankton groups
- any number of macrophyte groups
- ammonium
- nitrate-nitrite
- bioavailable phosphorus (SRP)
- labile dissolved organic matter
- refractory dissolved organic matter
- labile particulate organic matter
- refractory particulate organic matter
- total inorganic carbon
- alkalinity
- total iron
- dissolved oxygen
- organic sediments
- LDOM-P and LDOM-N
- LPOM-P and LPOM-N
- RDOM-P and RDOM-N
- RPOM-P and RPOM-N
- any # of CBODN and CBODP groups

Columbia Slough, Oregon – macrophyte model





Model set up

Download model zip file

Unzip file into respective directories

Copy model executables into example directories, let's look at the DeGray Reservoir example

examples	11/17/2013 11:44 PM	File folder	
Excel macro utility for writing files in W2 fo...	11/17/2013 11:45 PM	File folder	
executables	11/17/2013 11:45 PM	File folder	
source	11/17/2013 11:45 PM	File folder	
W2ControlGUI	11/17/2013 11:45 PM	File folder	
W2tools post-processor integrated with W...	11/17/2013 11:45 PM	File folder	
waterbalance	11/17/2013 11:45 PM	File folder	
v37.zip	10/7/2013 10:18 AM	Compressed (zippe...	35,127 KB
W2_Version_3.71_Release_Notes.pdf	10/3/2013 12:28 PM	Adobe Acrobat Doc...	470 KB
W2V3 manual371_rev12.pdf	10/7/2013 10:03 AM	Adobe Acrobat Doc...	12,462 KB

Model set-up

Develop the Model Grid – this involves developing a bathymetry file for each water body. Inputs are in text file format or csv format

CSV file format

Excel format – use Excel macro utility to write out as a csv file

Model set-up: CSV format

$																				
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
DLX	1046.4	1046.4	1046.4	965.9	965.9	764.7	764.7	1046.4	1046.4	1073.2	1073.2	1073.2	1126.9	1126.9	1180.5	1180.5	1180.5	912.2	912.2	912.2
ELWS	430.1	430.1	430.1	430.1	430.1	430.1	430.1	430.1	430.1	430.1	430.1	430.1	430.1	430.1	430.1	430.1	430.1	430.1	430.1	430.1
PHI0	3.142	3.142	3.142	3.142	3.142	3.142	3.142	3.142	3.142	3.142	3.142	3.142	3.142	3.142	3.142	3.142	3.142	3.142	3.142	3.142
FRIC	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70
LAYERH																				
0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0.5	0	335	335	335	335	364	364	362	362	327	327	327	423	423	438	438	438	472	472	472
0.5	0	231	231	231	231	254	254	255	255	312	312	312	406	406	426	426	426	466	466	466
0.5	0	228	228	228	228	243	243	248	248	298	298	298	388	388	413	413	413	460	460	460
0.5	0	224	224	224	224	231	231	241	241	285	285	285	370	370	400	400	400	453	453	453
0.5	0	220	220	220	220	219	219	233	233	272	272	272	351	351	387	387	387	446	446	446
0.5	0	215	215	215	215	206	206	225	225	259	259	259	332	332	373	373	373	439	439	439
0.5	0	202	202	202	202	188	188	208	208	247	247	247	324	324	359	359	359	431	431	431
0.5	0	192	192	192	192	161	161	199	199	234	234	234	291	291	345	345	345	422	422	422
0.5	0	173	173	173	173	142	142	189	189	222	222	222	269	269	330	330	330	414	414	414
0.5	0	0	0	130	130	130	130	178	178	208	208	208	247	247	315	315	315	404	404	404
0.5	0	0	0	0	125	125	125	166	166	195	195	195	223	223	298	298	298	395	395	395
0.5	0	0	0	0	0	120	120	153	153	181	181	181	199	199	282	282	282	384	384	384
0.5	0	0	0	0	0	0	110	139	139	167	167	167	173	173	265	265	265	372	372	372
0.5	0	0	0	0	0	0	0	135	135	151	151	151	145	145	246	246	246	360	360	360
0.5	0	0	0	0	0	0	0	0	130	134	134	134	116	116	227	227	227	346	346	346
0.5	0	0	0	0	0	0	0	0	0	114	114	114	100	110	209	209	209	330	330	330
0.5	0	0	0	0	0	0	0	0	0	0	40	100	90	100	184	184	184	311	311	311
0.5	0	0	0	0	0	0	0	0	0	0	0	40	80	90	160	160	160	288	288	288
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0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
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0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

$																				
	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38		
DLX	804.9	804.9	804.9	804.9	804.9	858.5	858.5	858.5	1006.1	1006.1	457.3	457.3	724.4	724.4	724.4	804.9	804.9	804.9		
ELWS	430.1	430.1	430.1	430.1	430.1	430.1	430.1	430.1	430.1	430.1	430.1	430.1	430.1	430.1	430.1	430.1	430.1	430.1		
PHI0	3.142	3.142	3.142	3.142	3.142	3.142	3.142	3.142	3.142	3.142	3.142	3.142	4.7	4.7	4.7	4.7	4.7	4.7		
FRIC	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70		
LAYERH																			K	ELEV
0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	
0.5	490	490	457	457	457	501	501	501	516	516	487	0	0	242	242	320	320	0	2	
0.5	486	486	453	453	453	498	498	498	509	509	483	0	0	234	234	318	318	0	3	
0.5	482	482	449	449	449	494	494	494	502	502	480	0	0	226	226	316	316	0	4	
0.5	477	477	444	444	444	491	491	491	495	495	476	0	0	219	219	314	314	0	5	
0.5	472	472	440	440	440	487	487	487	488	488	473	0	0	211	211	312	312	0	6	
0.5	467	467	435	435	435	484	484	484	481	481	467	0	0	202	202	309	309	0	7	
0.5	462	462	430	430	430	480	480	480	473	473	465	0	0	185	185	305	305	0	8	
0.5	457	457	425	425	425	476	476	476	465	465	461	0	0	176	176	303	303	0	9	
0.5	451	451	420	420	420	472	472	472	458	458	457	0	0	167	167	301	301	0	10	
0.5	445	445	415	415	415	468	468	468	450	450	453	0	0	157	157	298	298	0	11	
0.5	440	440	409	409	409	465	465	465	442	442	449	0	0	147	147	296	296	0	12	
0.5	433	433	404	404	404	460	460	460	434	434	445	0	0	136	136	294	294	0	13	
0.5	427	427	397	397	397	456	456	456	426	426	440	0	0	125	125	291	291	0	14	
0.5	419	419	391	391	391	451	451	451	417	417	436	0	0	113	113	290	290	0	15	
0.5	412	412	384	384	384	447	447	447	408	408	431	0	0	101	101	287	287	0	16	
0.5	404	404	377	377	377	442	442	442	400	400	426	0	0	87	87	285	285	0	17	
0.5	396	396	369	369	369	436	436	436	391	391	422	0	0	74	74	283	283	0	18	
0.5	386	386	361	361	361	431	431	431	381	381	417	0	0	58	58	281	281	0	19	
0.5	376	376	352	352	352	426	426	426	372	372	411	0	0	41	41	278	278	0	20	
0.5	364	364	342	342	342	420	420	420	362	362	406	0	0	20	30	276	276	0	21	
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0.5	334	334	317	317	317	407	407	407	342	342	394	0	0	0	0	66	66	0	23	
0.5	313	313	302	302	302	400	400	400	331	331	388	0	0	0	0	0	18	0	24	
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0.5	68	68	251	251	251	384	384	384	308	308	375	0	0	0	0	0	0	0	26	
0.5	39	39	72	72	72	375	375	375	297	297	368	0	0	0	0	0	0	0	27	
0.5	0	30	34	34	54	365	365	365	284	284	360	0	0	0	0	0	0	0	28	
0.5	0	0	30	30	40	353	353	353	271	271	352	0	0	0	0	0	0	0	29	
0.5	0	0	0	20	30	340	340	340	257	257	344	0	0	0	0	0	0	0	30	
0.5	0	0	0	0	20	322	322	322	243	243	334	0	0	0	0	0	0	0	31	
0.5	0	0	0	0	0	296	296	296	227	227	324	0	0	0	0	0	0	0	32	
0.5	0	0	0	0	0	100	134	134	210	210	312	0	0	0	0	0	0	0	33	
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0.5	0	0	0	0	0	0	50	50	171	171	285	0	0	0	0	0	0	0	35	
0.5	0	0	0	0	0	0	0	30	147	147	266	0	0	0	0	0	0	0	36	
0.5	0	0	0	0	0	0	0	0	117	117	241	0	0	0	0	0	0	0	37	
0.5	0	0	0	0	0	0	0	0	75	75	197	0	0	0	0	0	0	0	38	
0.5	0	0	0	0	0	0	0	0	0	57	50	0	0	0	0	0	0	0	39	
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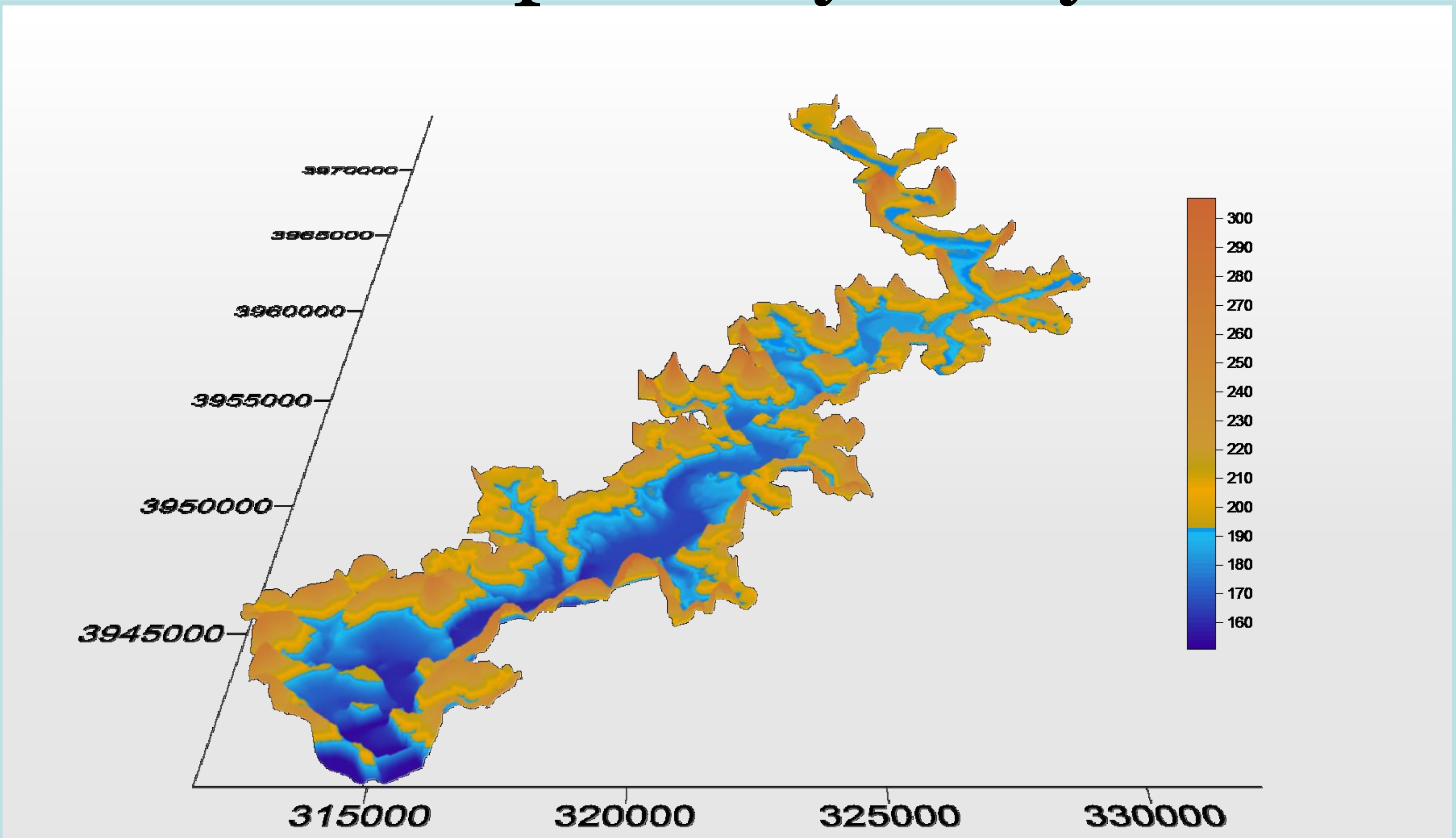
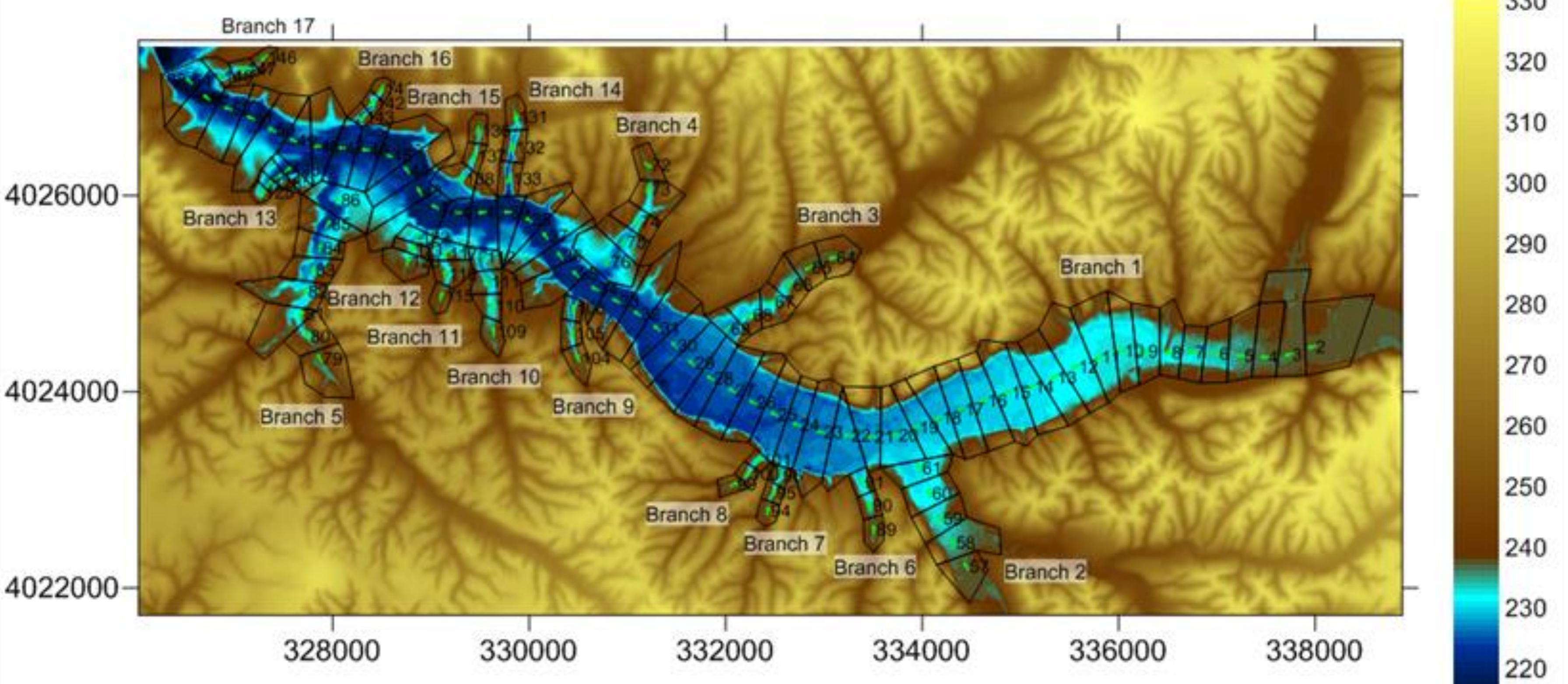
Model set-up: Bathymetry



Bathymetry

- Topographic map
- Sediment range surveys
- Volume-area-elevation table
- Cross-sections for river



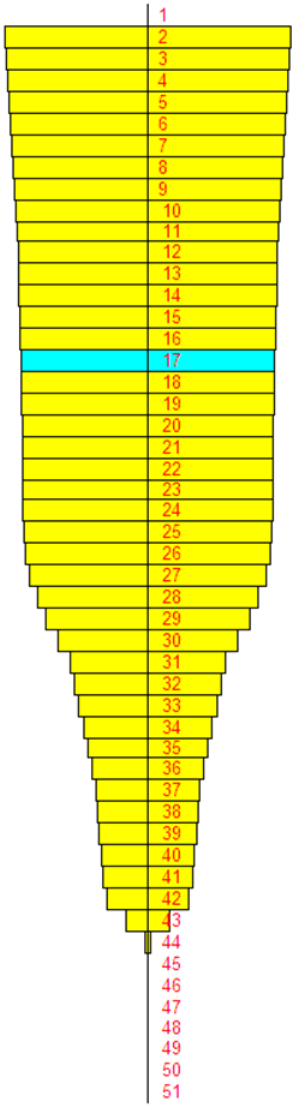
Note

CE-QUAL-W2 allows the specification of

- **waterbodies** (a collection of model branches that have similar turbulence closure and water quality parameter values and meteorological forcing; a river and a reservoir)
- **branches** (a collection of model segments with variable model slope; a river with different slopes or a reservoir with multiple sidearms)
- **segments** (a longitudinal segment of length Δx)
- **layers** (a vertical layer of height Δz).

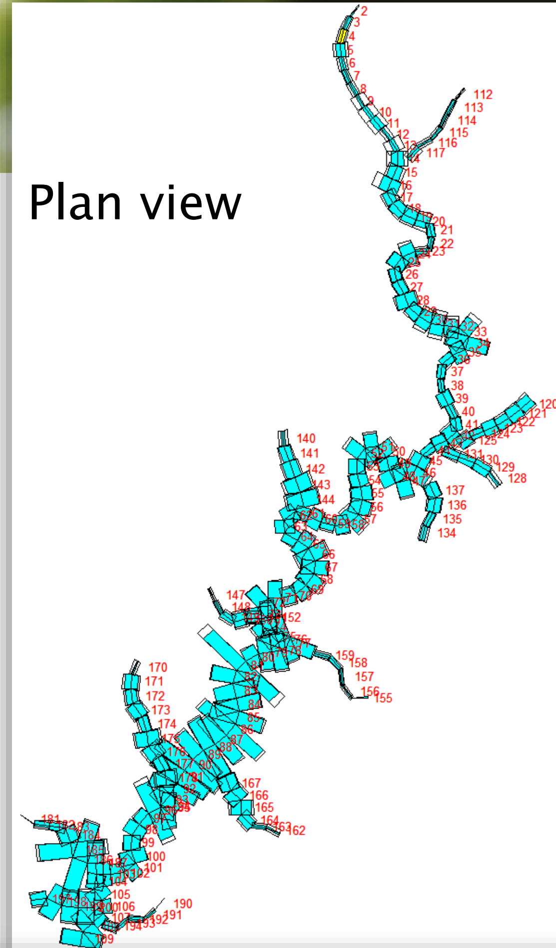
Model Set-up: Grid

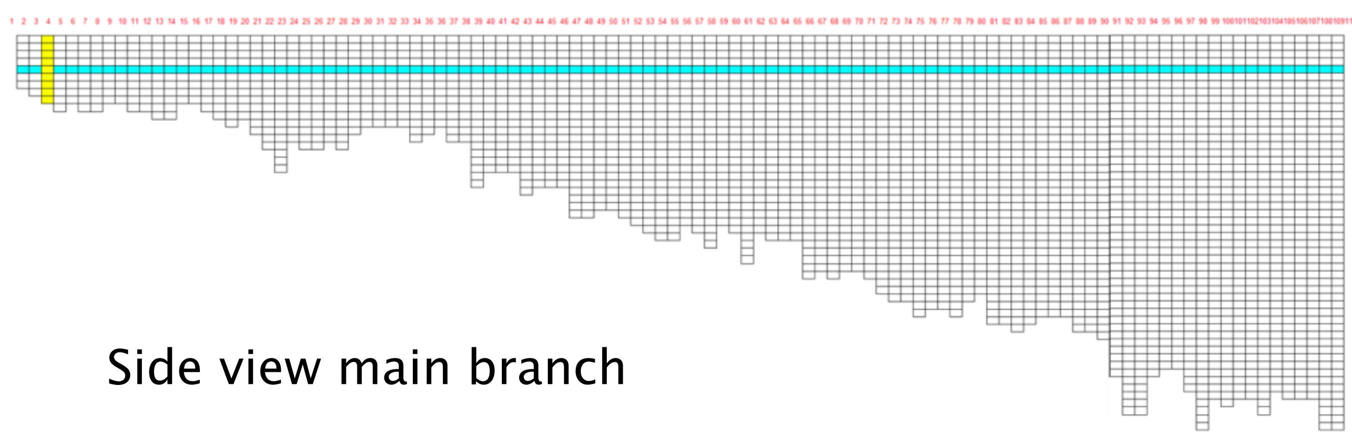
200 model segments, 13 branches, 500 m segment length, 1 m vertical layer height, 51 vertical layers



Segment end view

Plan view





Side view main branch

Model set-up

Construct all boundary condition files – flow rates, temperatures, and concentrations for all inflows, meteorological conditions for each waterbody, water levels for head BCs, shading for each segment, wind sheltering file for segments as a f(time)

All input files are text files; Use Excel macro to develop model input files

Boundary condition and calibration data

Model set-up data

Meteorological data
- Air temp, dew point temp, wind speed/direction, cloud cover, solar radiation

Inflows

Outflows

Water quality boundary data (temp, nutrients, organic matter, DO, SS, etc.)

Model calibration data

Water level data

Temperature profiles and continuous probes in outflow

Dissolved oxygen and nutrient profiles and grab samples

Algae data

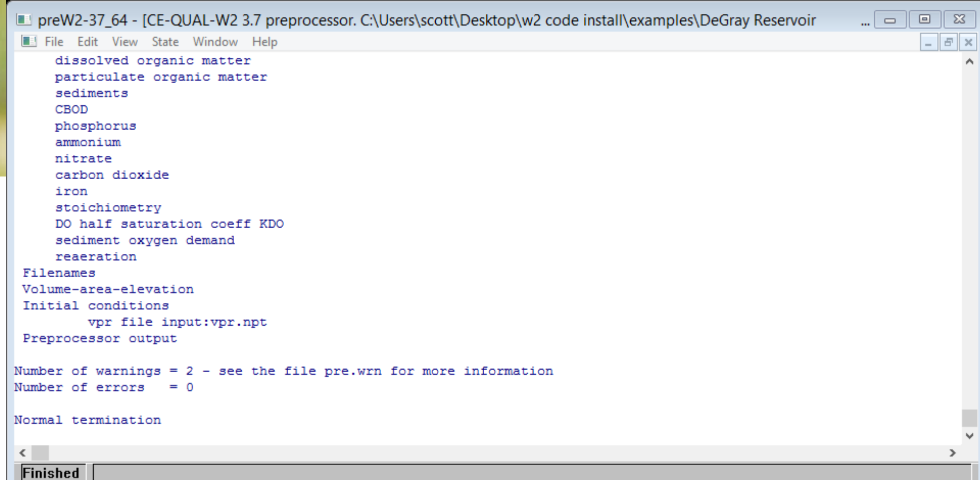
Secchi disk depth

….

Model set-up

Edit the Control File – this file, **w2_con.npt**, is the central file for describing how the model will run. This file tells the code when the model starts, ends, where the inflows/outflows are located, names of files, kinetic parameters, and items you cannot even imagine. Open this file in a text editor or open it using the GUI **W2Control37.exe**

Model set-up

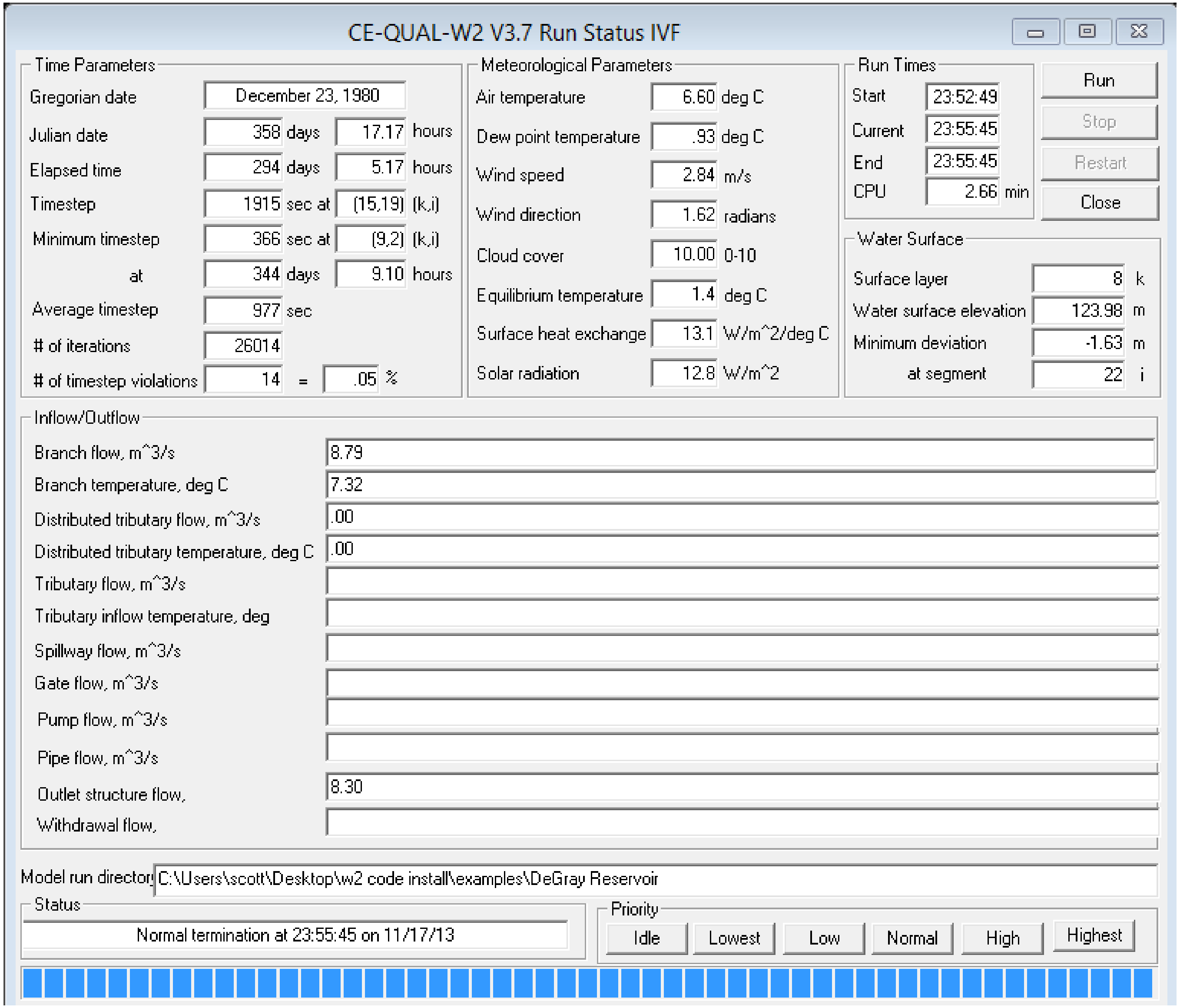


Run the Preprocessor – this file, **preW2-37_64.exe**, checks for model errors in the control file, bathymetry file, and all boundary condition files. Double click on the executable and look at the preprocessor screen. This file writes out between 1 to 3 files: **pre.opt** (an echo of input data and other useful items), **pre.err** (if fatal errors), and **pre.wrn** (if warnings). Make sure you look at **pre.wrn** and **pre.err** files.

Model run

Run the W2 Model – the file **w2_ivf64.exe** is the W2 model code. Double click on the w2 executable and notice the dialog box and the dynamic animation boxes for the simulation.

Model run

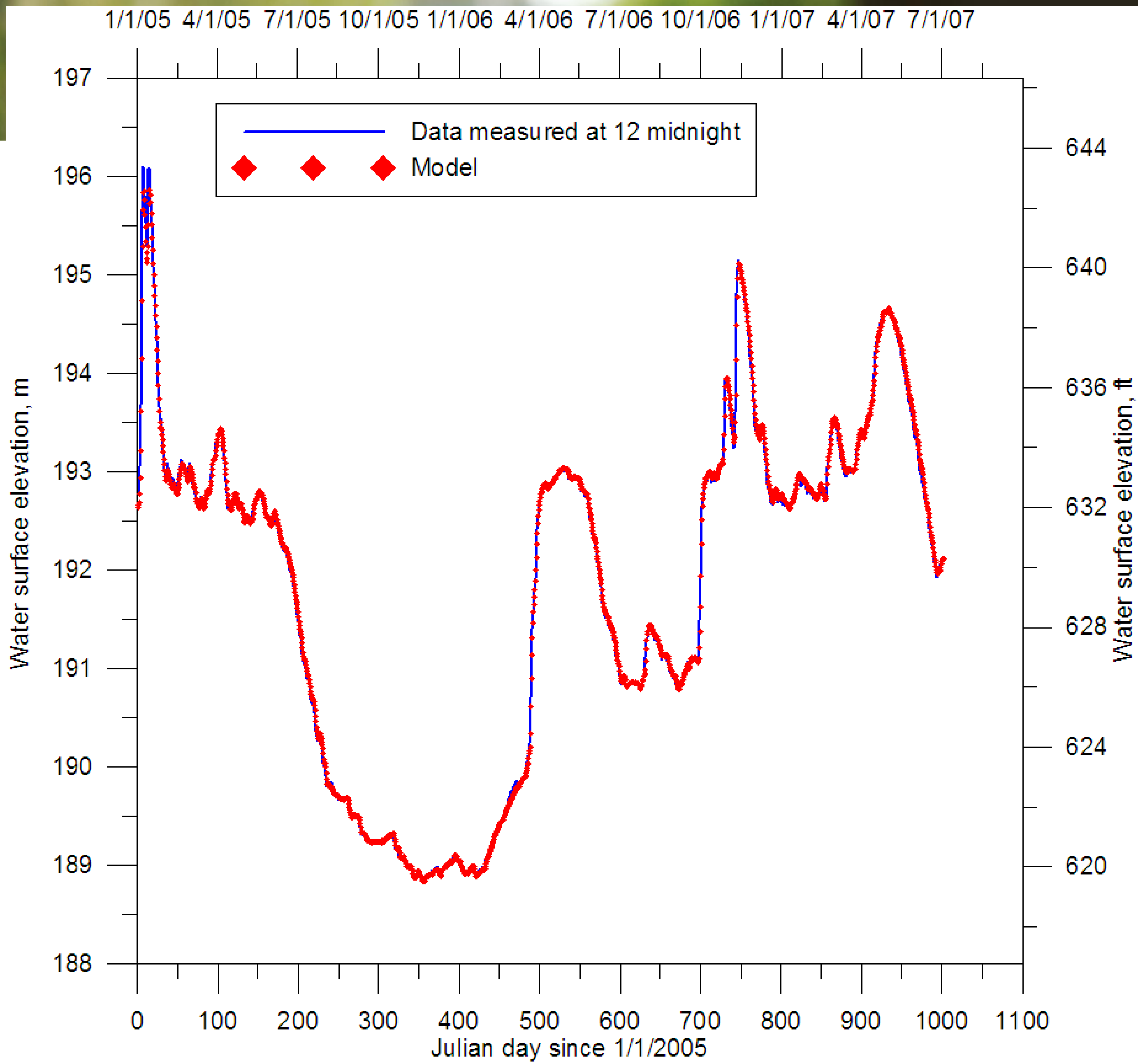

CE-QUAL-W2 V3.7 Run Status IVF
Time Parameters
Gregorian date
December 23, 1980
Julian date
358 days
17.17 hours
Elapsed time
294 days
5.17 hours
Timestep
1915 sec at
(15,19) (k,i)
Minimum timestep
366 sec at
(9,2) (k,i)
at
344 days
9.10 hours
Average timestep
977 sec
# of iterations
26014
# of timestep violations
14 = .05 %
Meteorological Parameters
Air temperature
6.60 deg C
Dew point temperature
.93 deg C
Wind speed
2.84 m/s
Wind direction
1.62 radians
Cloud cover
10.00 0-10
Equilibrium temperature
1.4 deg C
Surface heat exchange
13.1 W/m^2/deg C
Solar radiation
12.8 W/m^2
Run Times
Start
23:52:49
Current
23:55:45
End
23:55:45
CPU
2.66 min
Run
Stop
Restart
Close
Water Surface
Surface layer
8 k
Water surface elevation
123.98 m
Minimum deviation
-1.63 m
at segment
22 i
Inflow/Outflow
Branch flow, m^3/s
8.79
Branch temperature, deg C
7.32
Distributed tributary flow, m^3/s
.00
Distributed tributary temperature, deg C
.00
Tributary flow, m^3/s
Tributary inflow temperature, deg
Spillway flow, m^3/s
Gate flow, m^3/s
Pump flow, m^3/s
Pipe flow, m^3/s
Outlet structure flow,
8.30
Withdrawal flow,
Model run director
C:\Users\scott\Desktop\w2 code install\examples\DeGray Reservoir
Status
Normal termination at 23:55:45 on 11/17/13
Priority
Idle
Lowest
Low
Normal
High
Highest

Evaluate model results

Evaluate OUTPUT files or Model Results – W2 outputs files have an extension 'opt'. Typical files include snapshot files (such as **snp.opt** – user defined name), time series files (such as **tsr_1_seg31.opt**) at a point, and spreadsheet files (such as **spr.opt**). Many of these can be used with Excel for easy plotting. You can use Tecplot360 or the w2_post post-processor for contour plots, animations, and profile plots.

Tenkiller Water Level

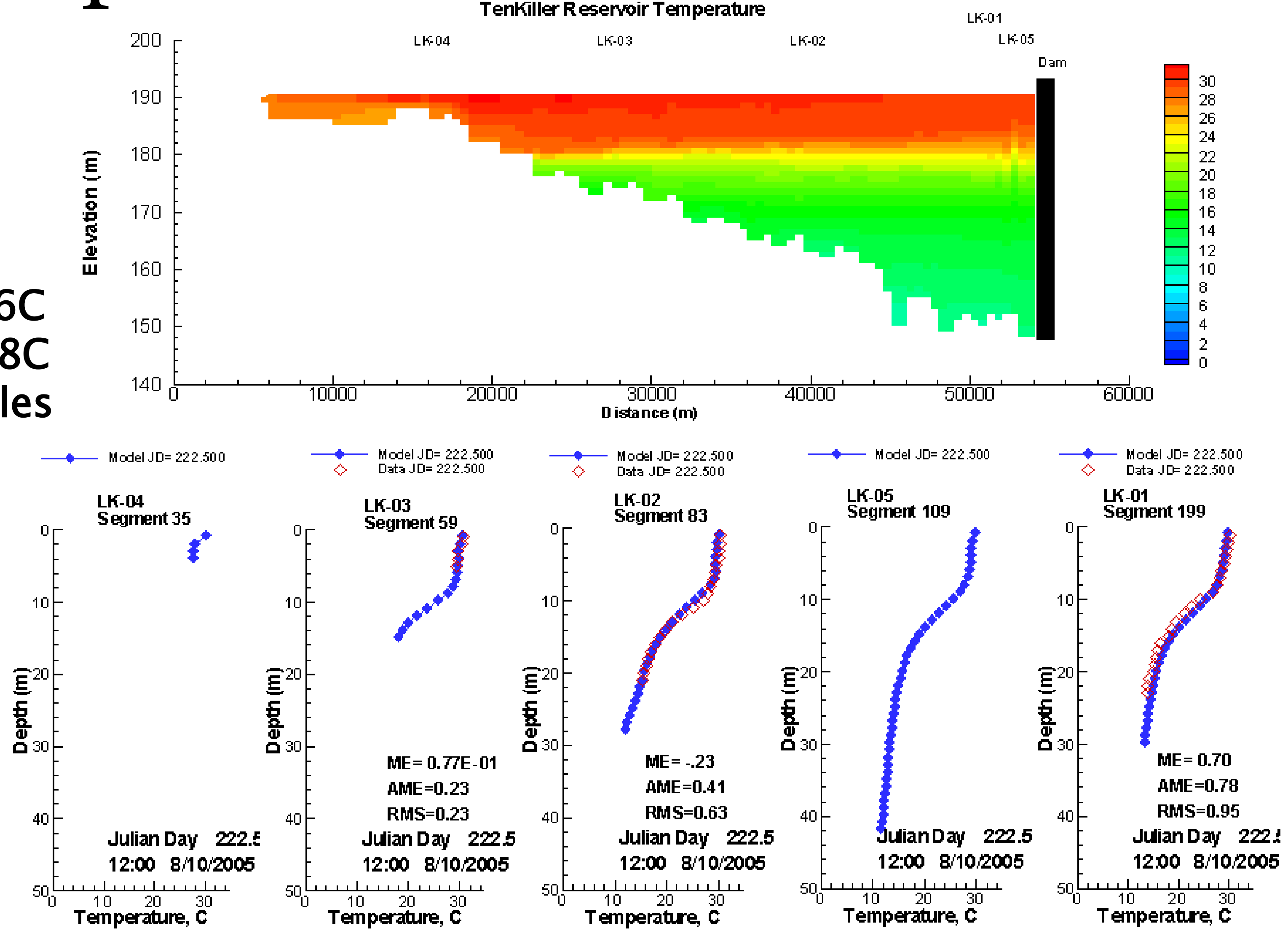
Water balance utility used for lake/reservoir water balance determination



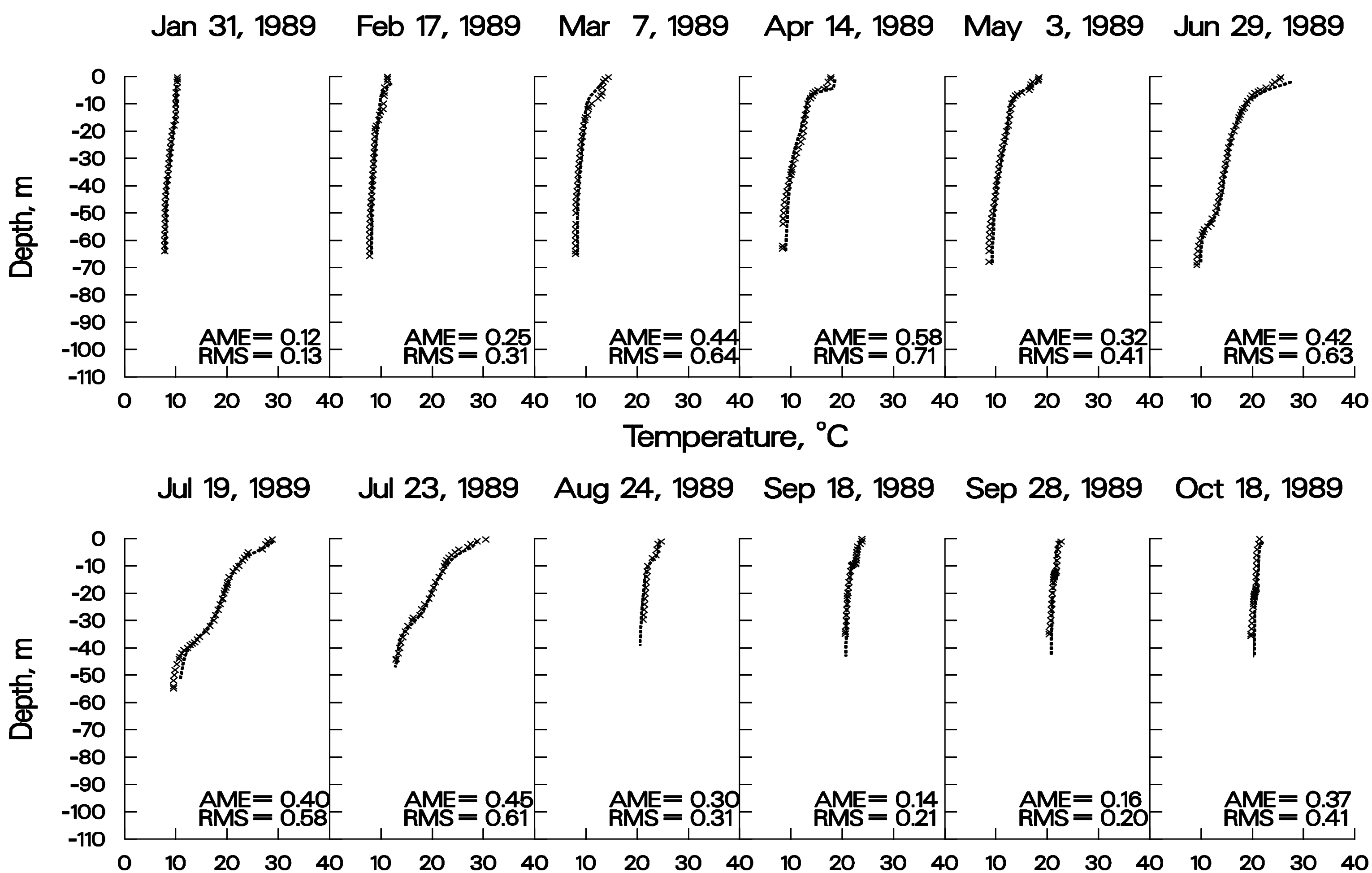
Location	# of comparisons, N	Mean error, m	Absolute mean error, m
Segment 109 at Tenkiller dam	1002	0.00	0.02

Temperature calibration

ME=-0.06C
AME=0.78C
117 profiles

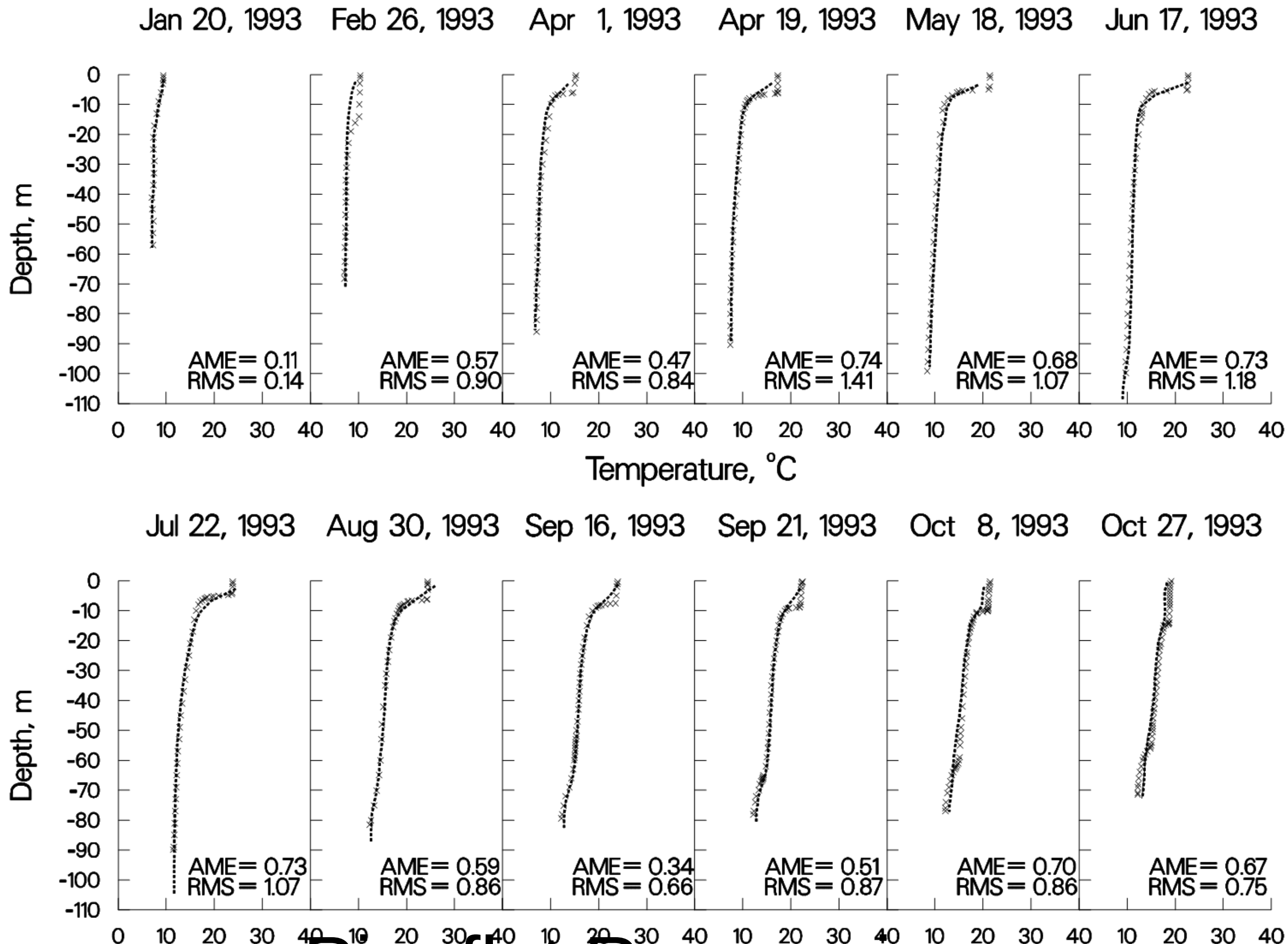


Thermal Calibration



Pineflat Reservoir

Thermal Calibration



Pineflat Reservoir

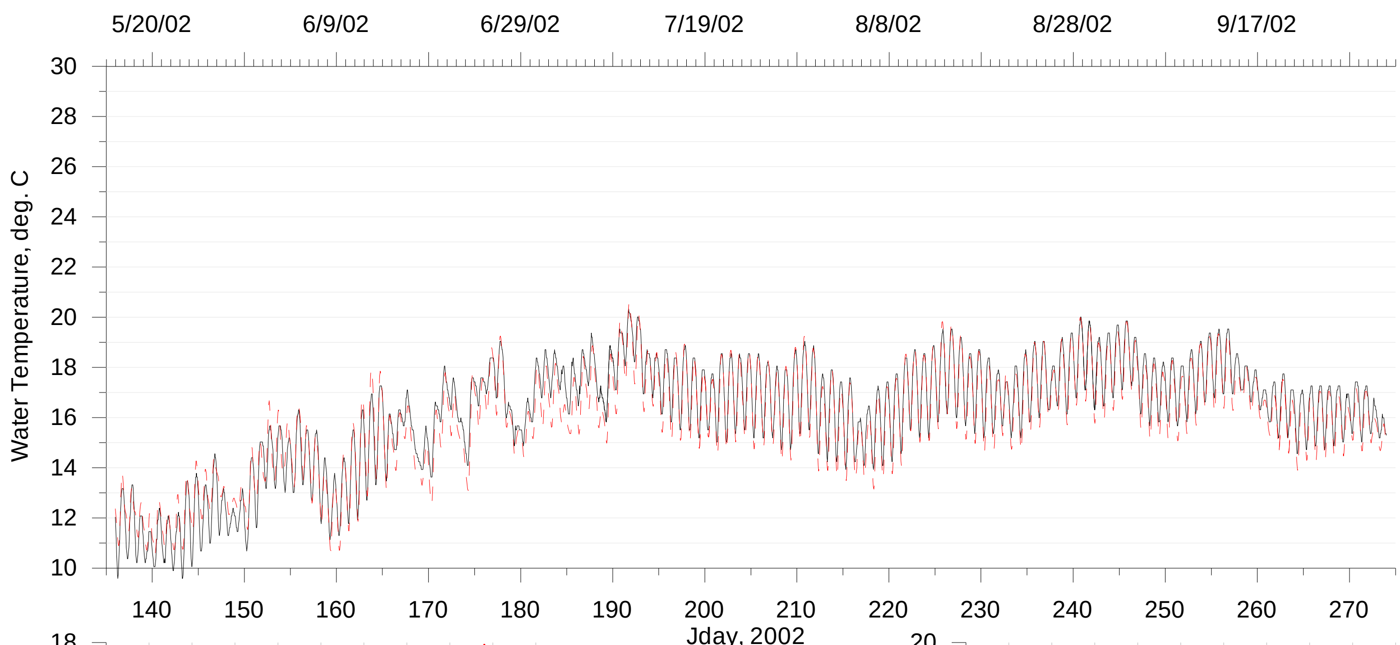
Thermal Calibration in Rivers

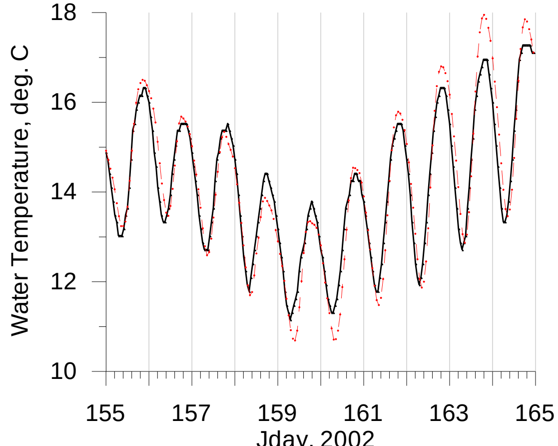
Easier than stratified systems
- why?

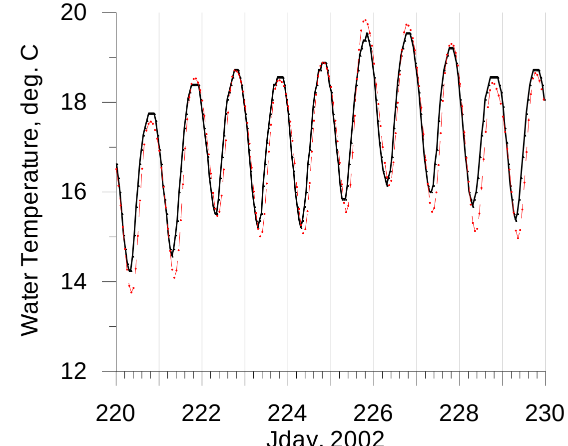
Successful comparison of model predictions to field data are dependent on surface area, depth, and of course correct meteorological conditions and boundary conditions

Upper Willamette River Temperature

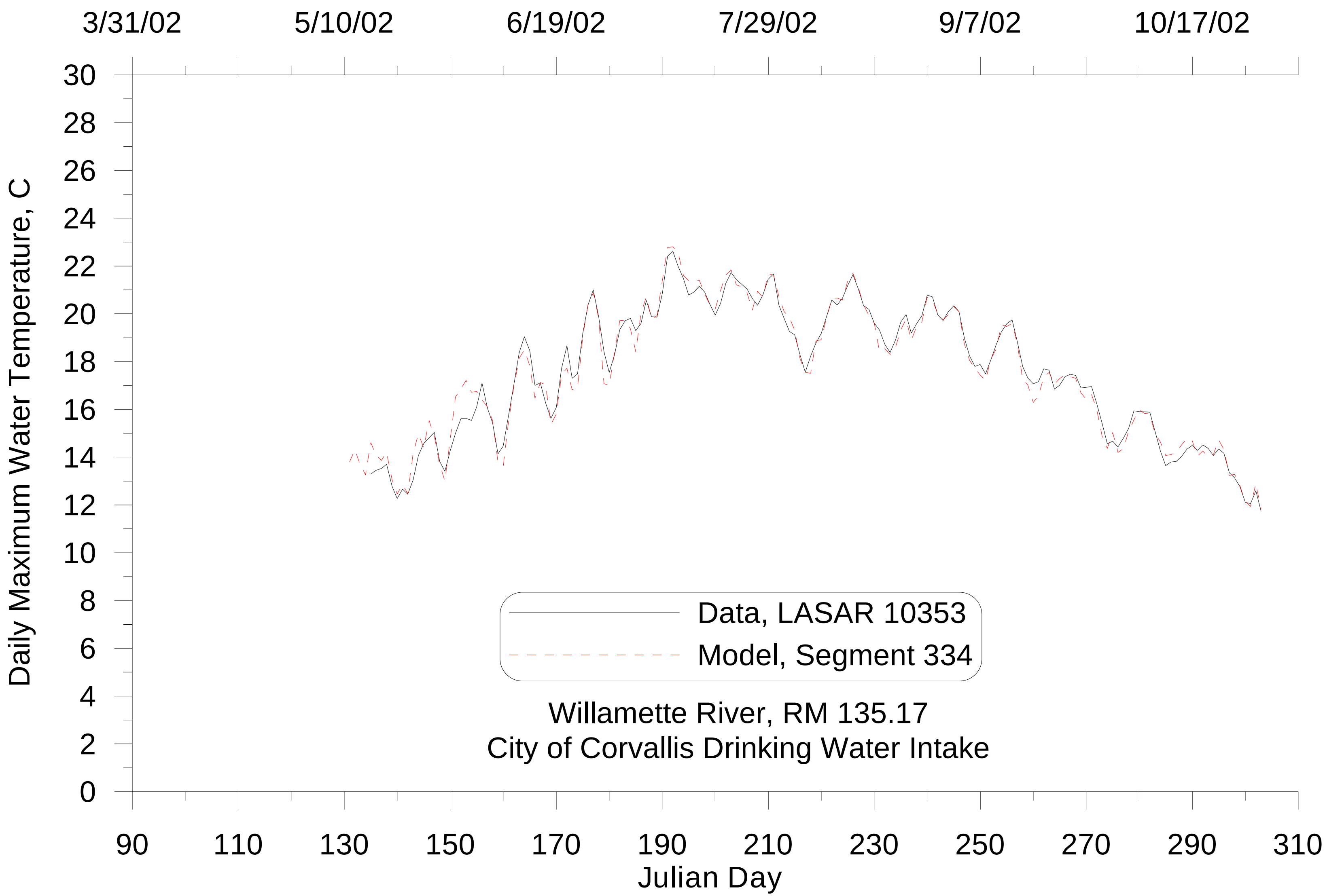
Water Temperature abv. McKenzie R. model RM 178, LASAR 28723. Segment 62.







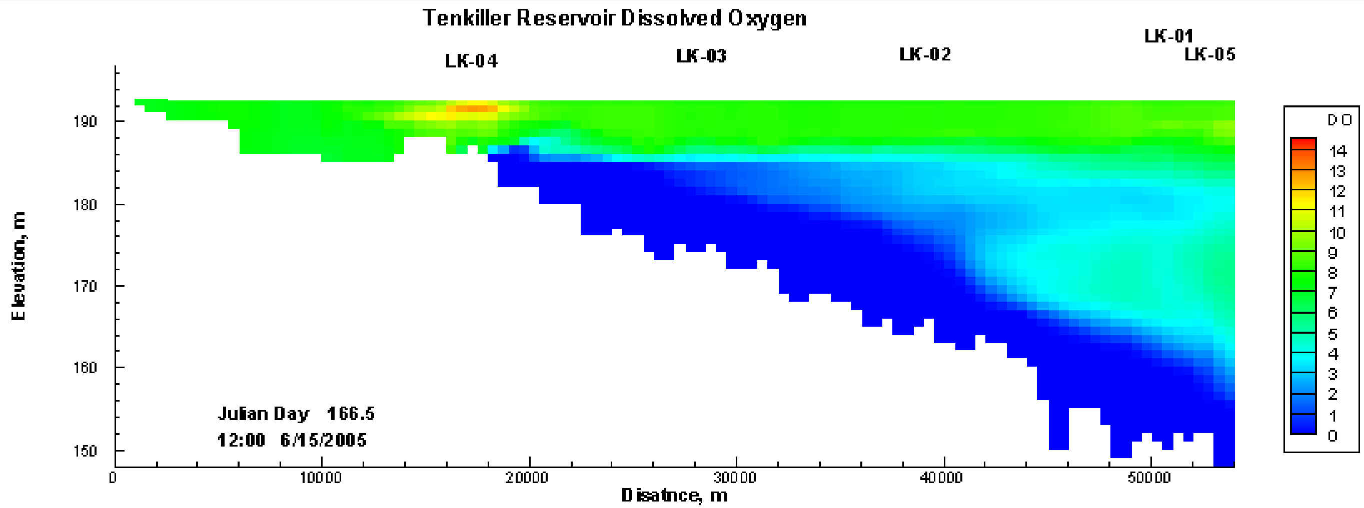
Upper Willamette River Daily Max Temperature

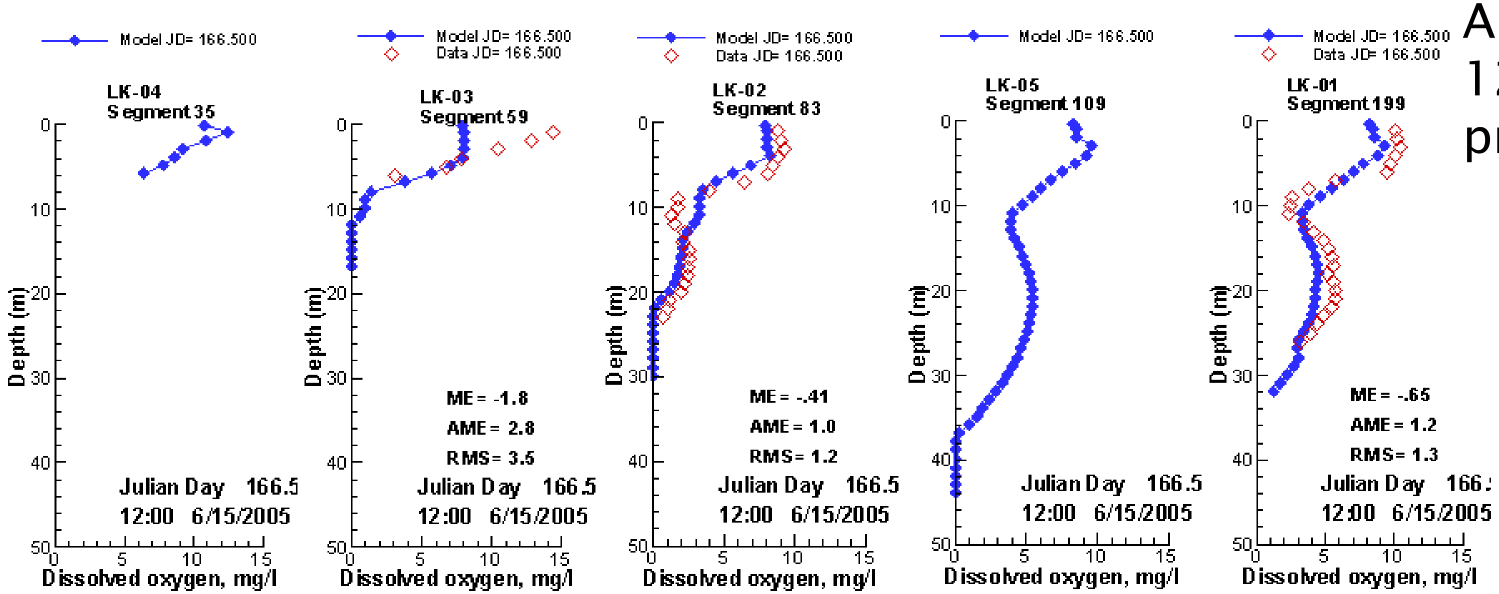


2001 Upper Willamette River Temperature Model – Data Error Statistics

Station Name	RM	Segment	#	ME, C	AME, C	RMS, C
Springfield	185.3	2	5040	0.016	0.040	0.051
abv_McKenzie	177.7	53	2362	-0.183	0.400	0.514
Harrisburg	162.0	156	5040	0.149	0.615	0.736
abv_Long Tom	151.6	227	5040	0.381	0.577	0.738
RM 147	147.4	255	5040	0.490	0.638	0.812
RM 141.7	142.4	287	5040	0.359	0.603	0.752
Corvallis	135.2	334	2520	0.206	0.485	0.619
Albany	120.2	434	2179	-0.109	0.370	0.472
Conser Rd	113.9	476	4967	0.023	0.454	0.580
River Rd	96.9	589	4958	-0.167	0.424	0.523
abv_rickreall	88.9	643	2520	0.126	0.630	0.824
Salem	84.7	666*	600	0.167	0.514	0.641

Dissolved oxygen calibration

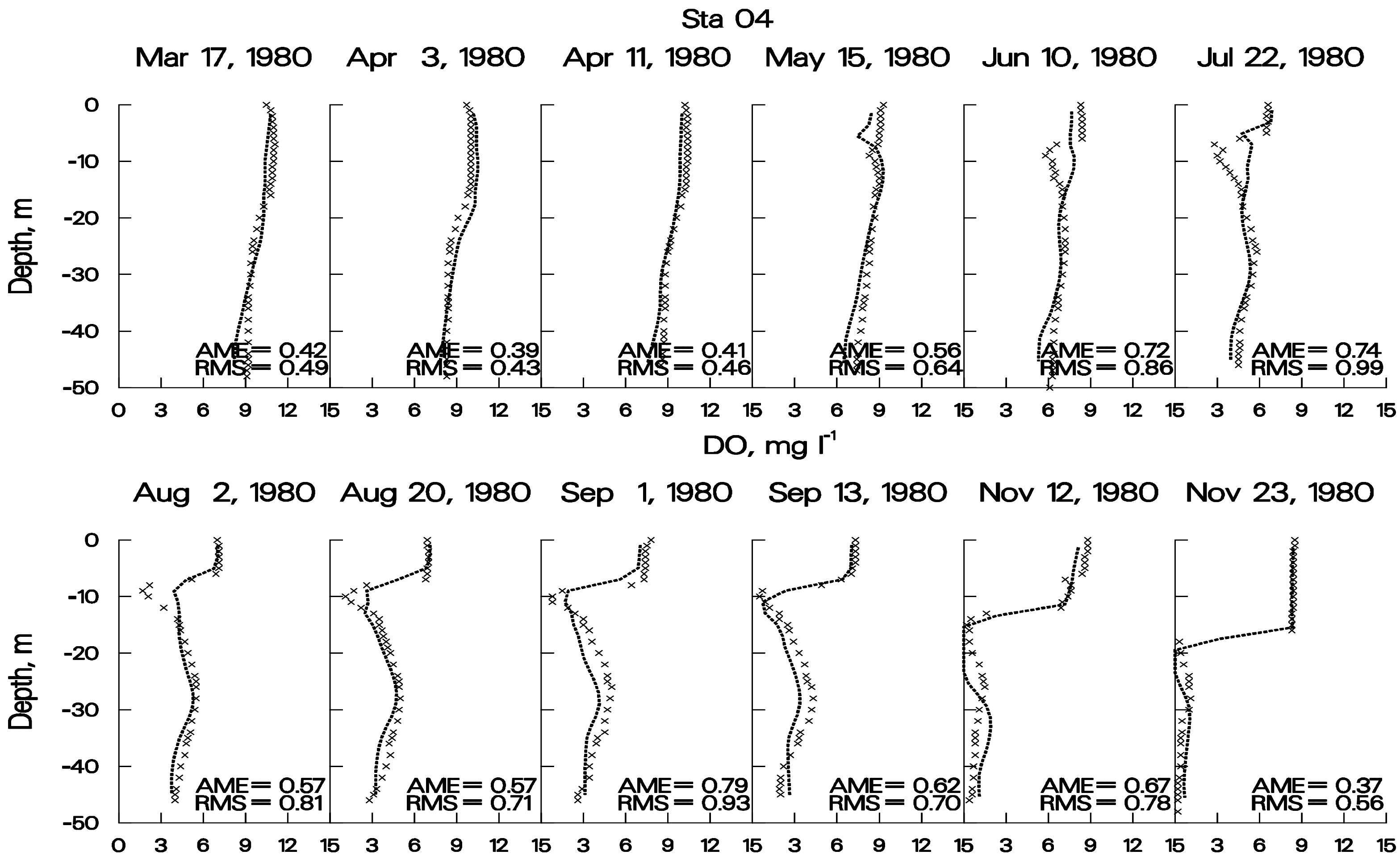




1.5 mg/l AME

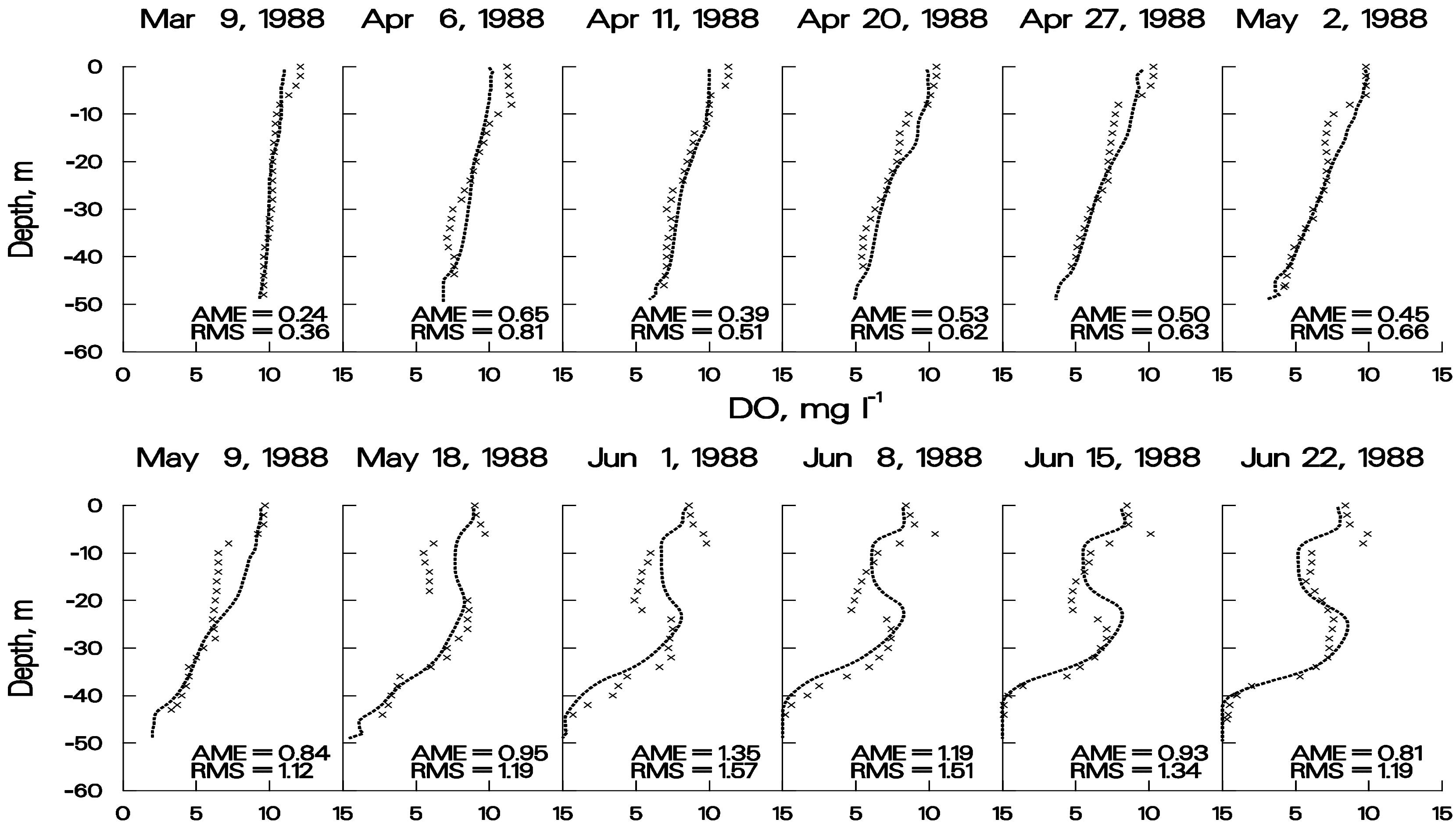
128 profiles

DO Calibration



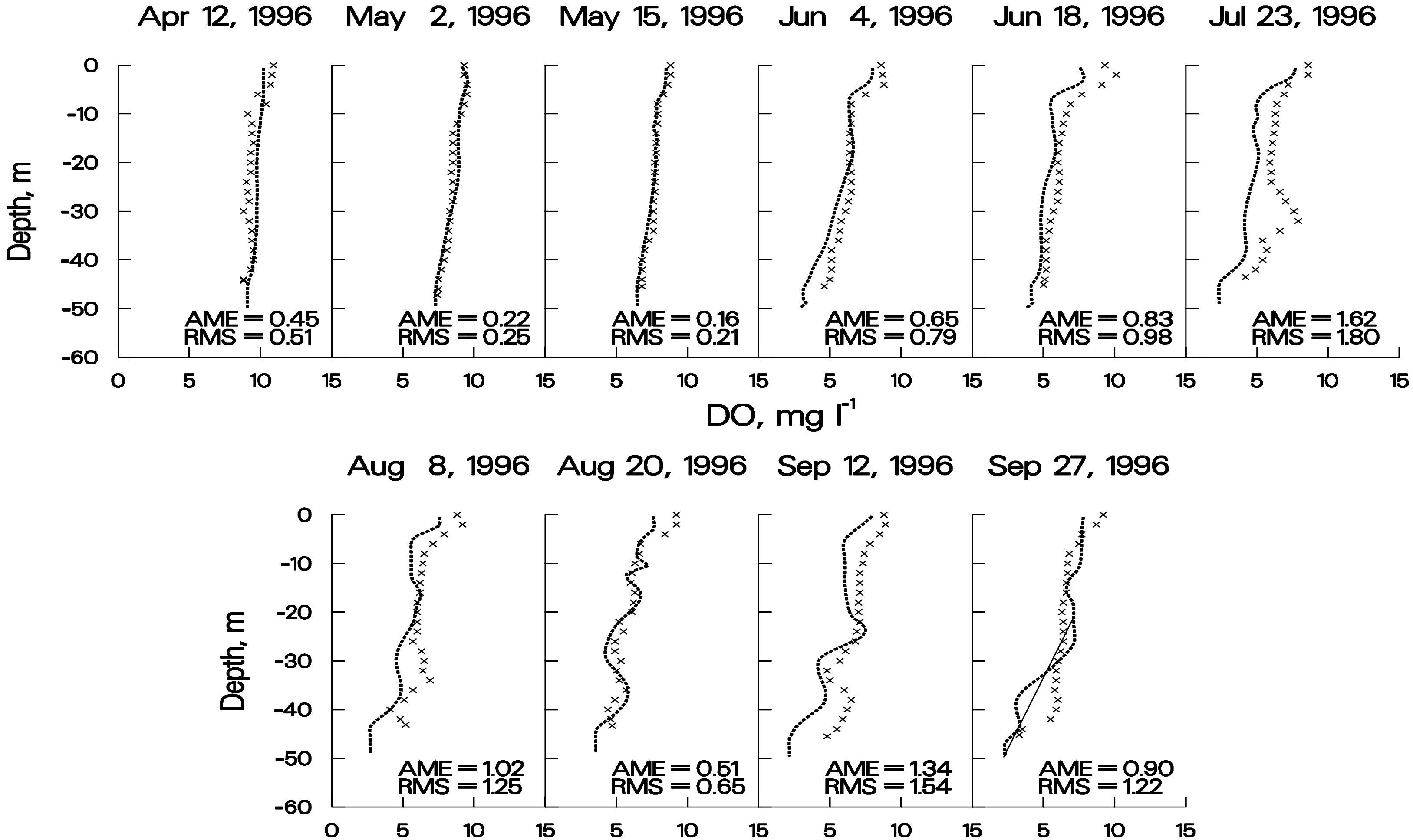
DeGray Reservoir

DO Calibration



Richard B. Russell Reservoir

DO Calibration

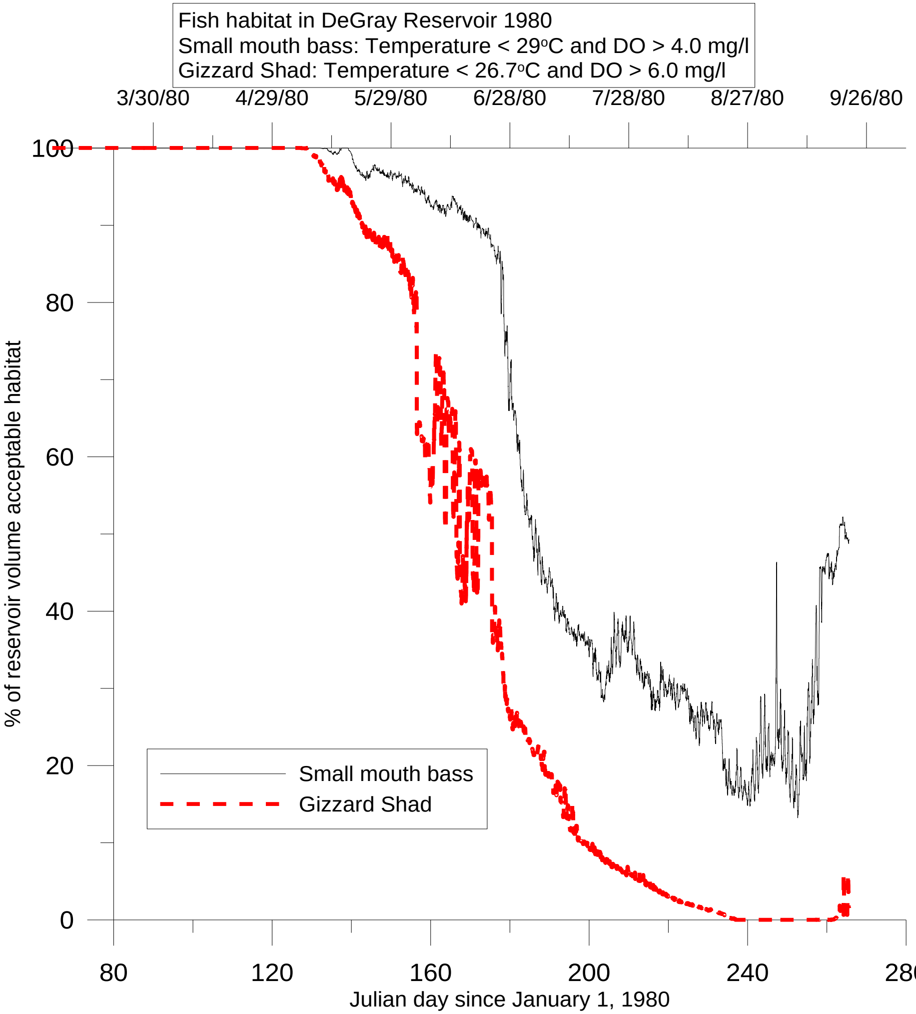


Richard B. Russell Reservoir

Analysis of Model Calibration

- Temperature and dissolved oxygen habitat volumes
  - Determine species habitat volumes based on temperature and dissolved oxygen criteria

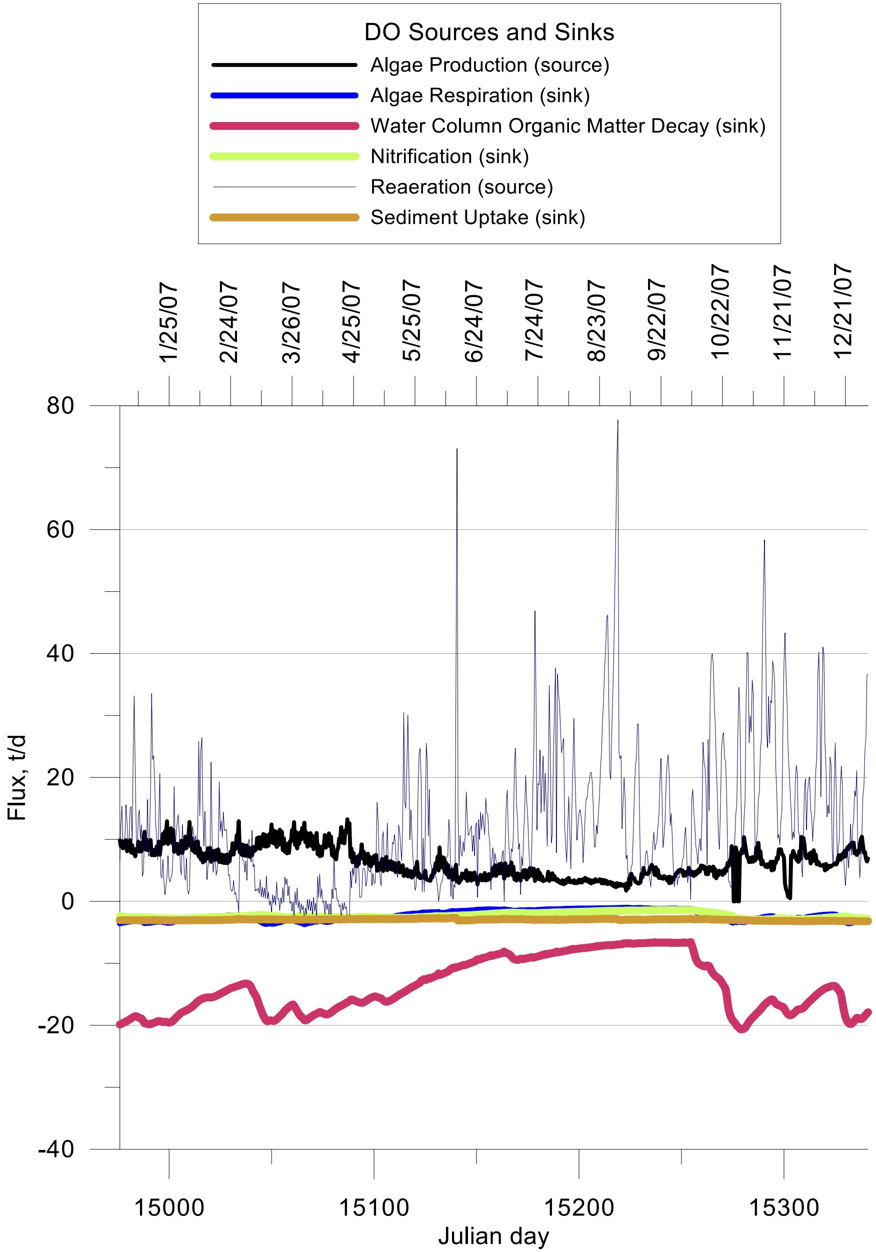
File: habitat3.opt in DeGray application



Analysis of Model Calibration

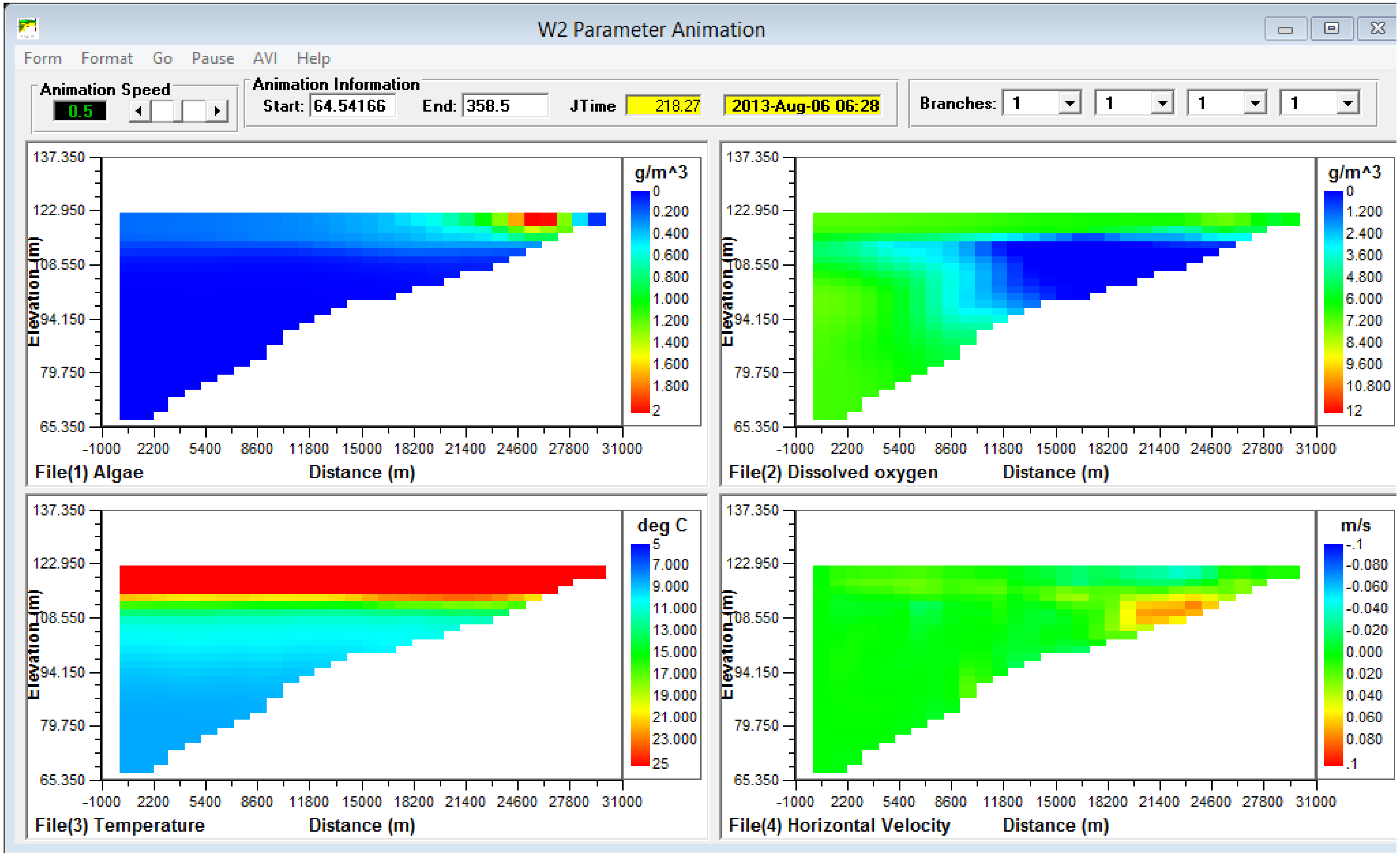
•I/O improvements: kinetic fluxes output – big picture look at model predictions

File: kwflux_jw1.opt and flx.opt in DeGray application

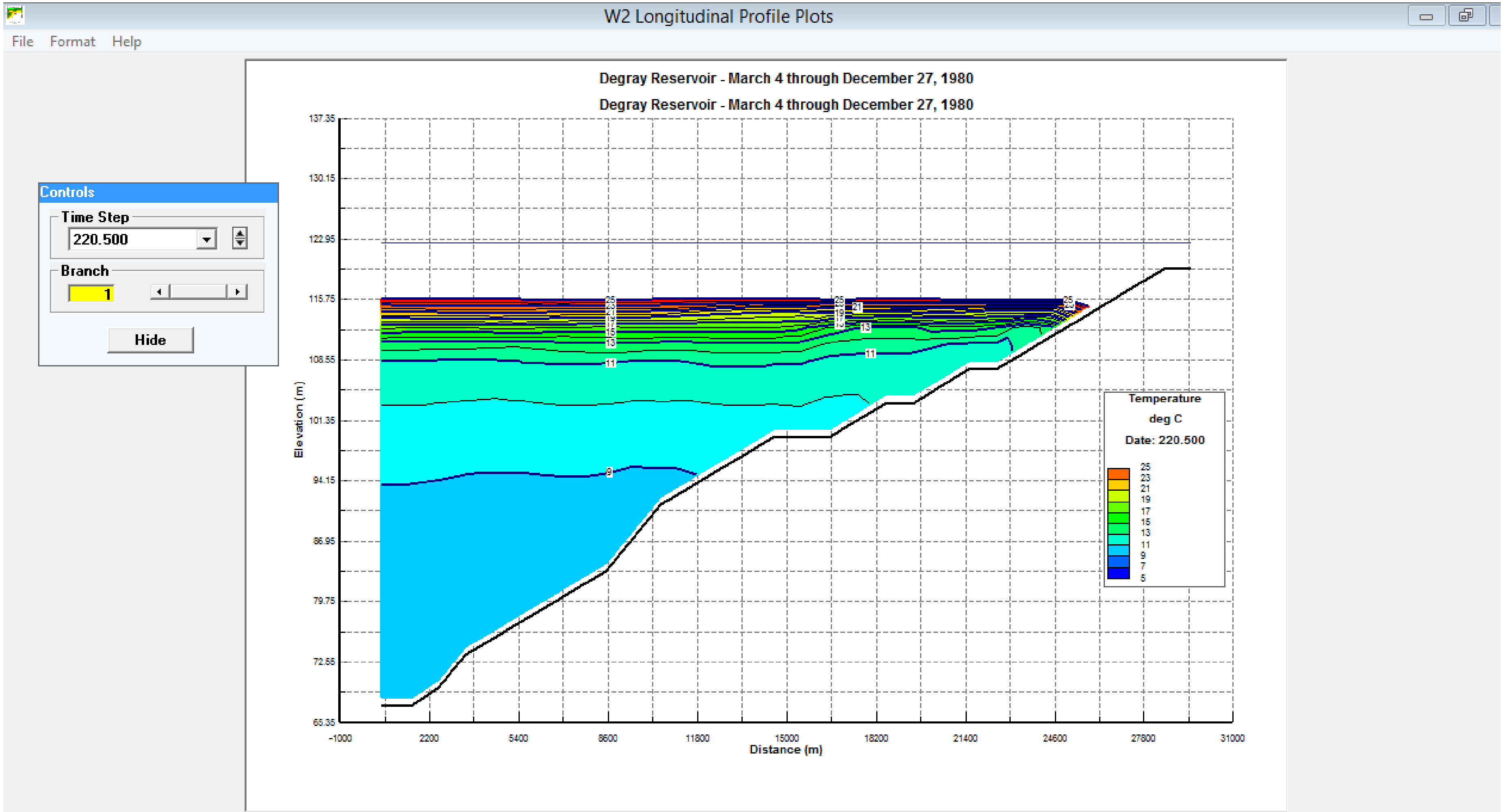


Use of model post-processor

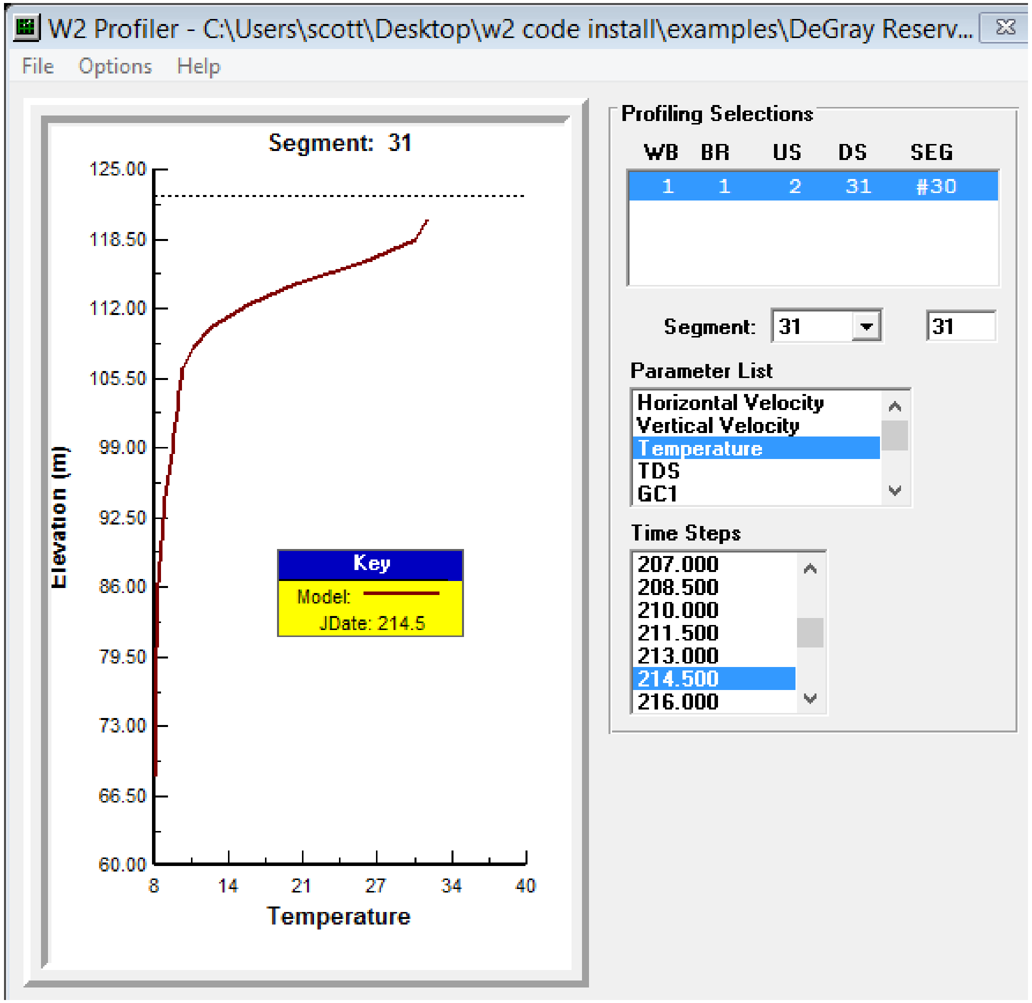
Animations – up to 4 animations at a time. Can generate AVI files.



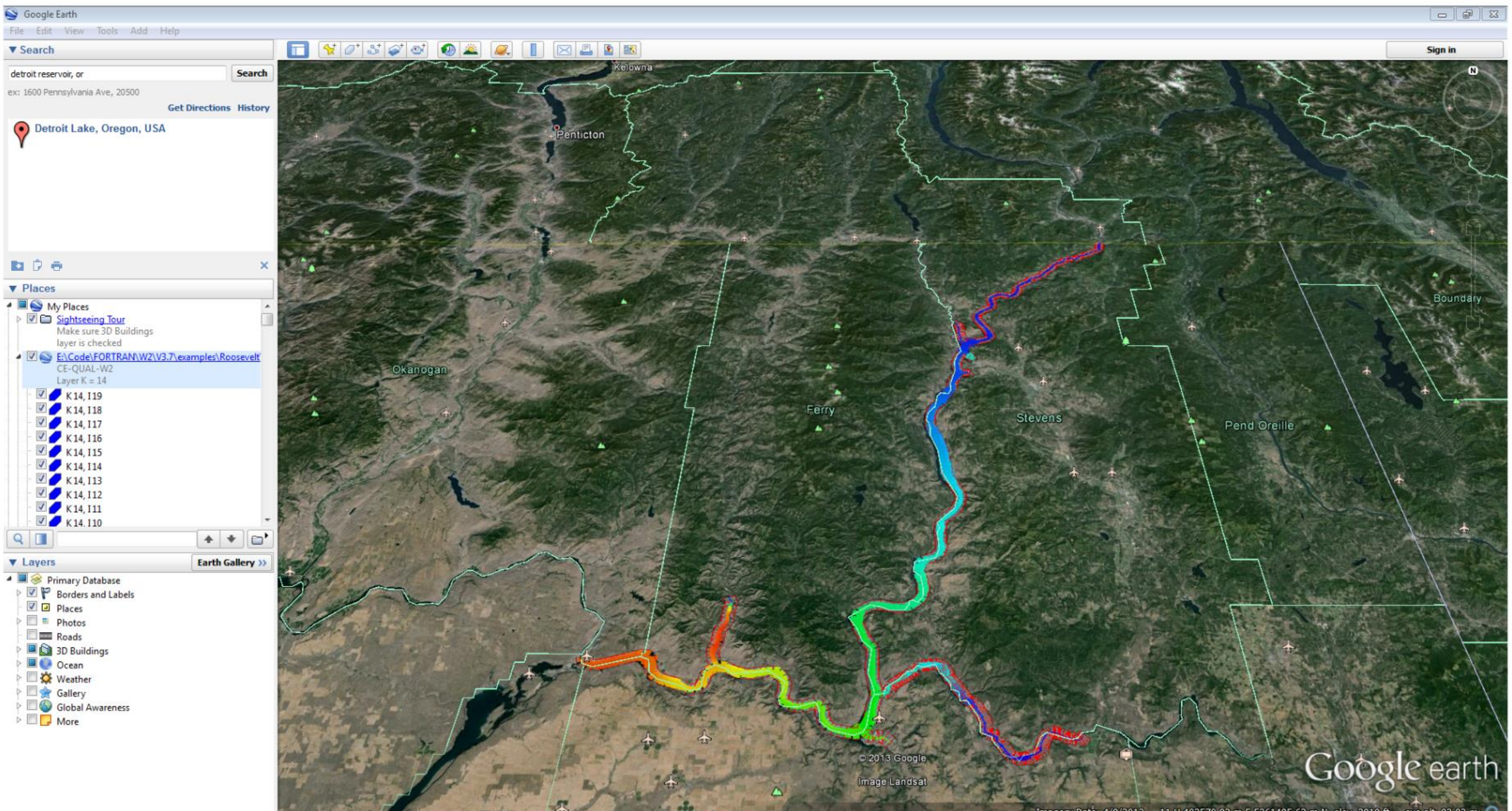
Model post-processor - contours



Model post-processor - profiles

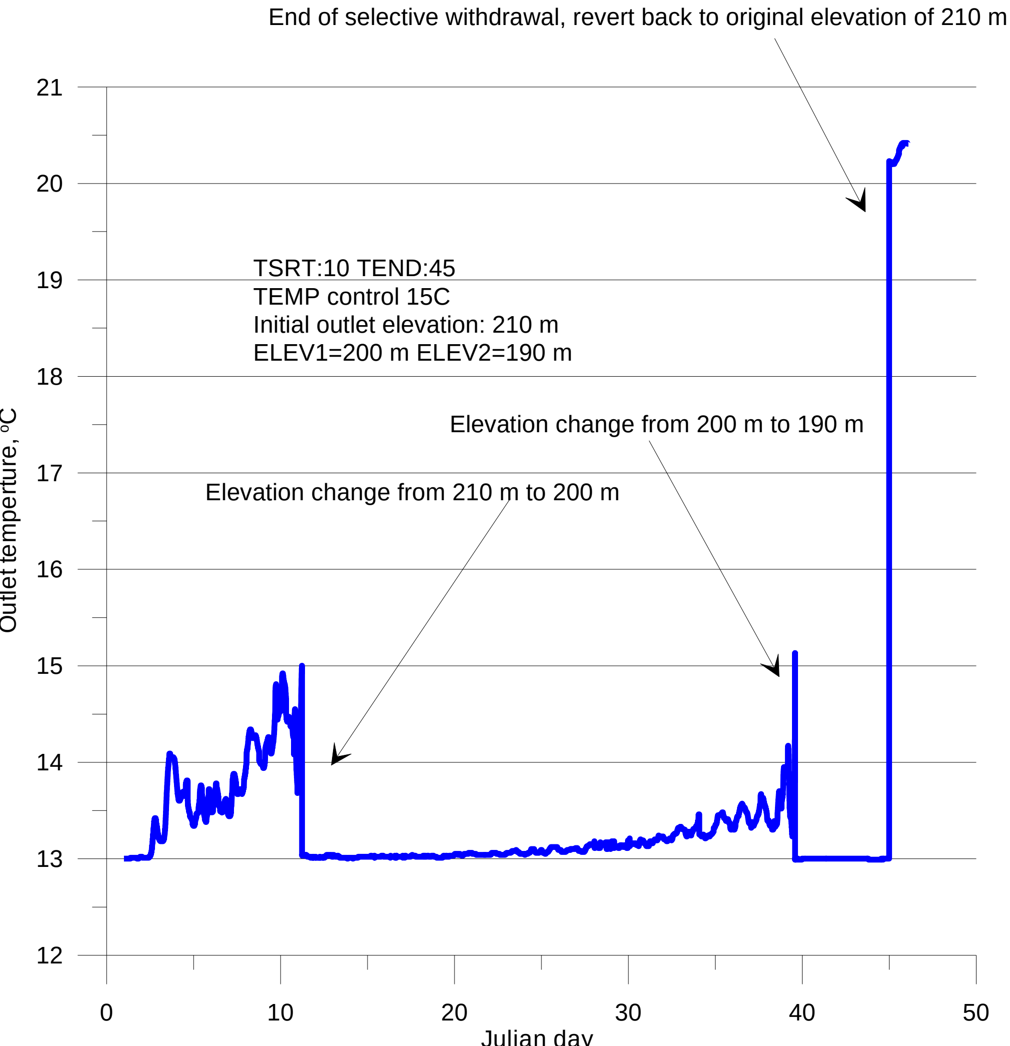


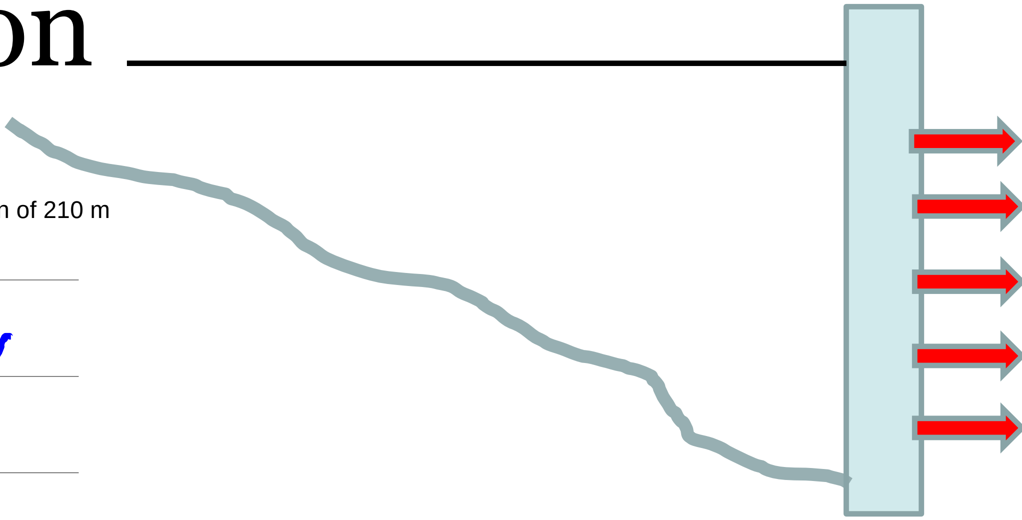
Model post-processor: Integration with Google Maps



Lake Roosevelt, WA, Water age

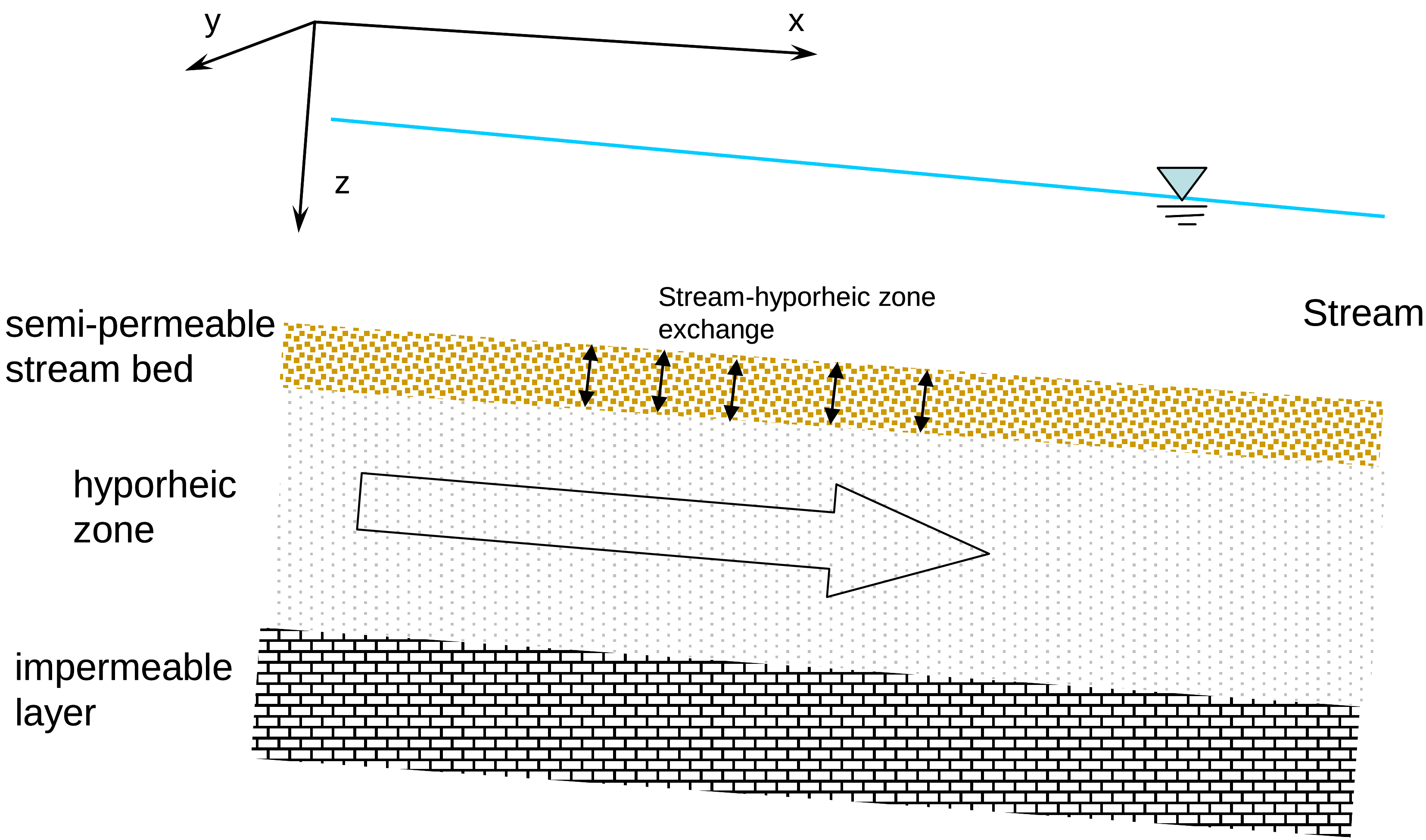
Auto-Port Selection





Current Directions

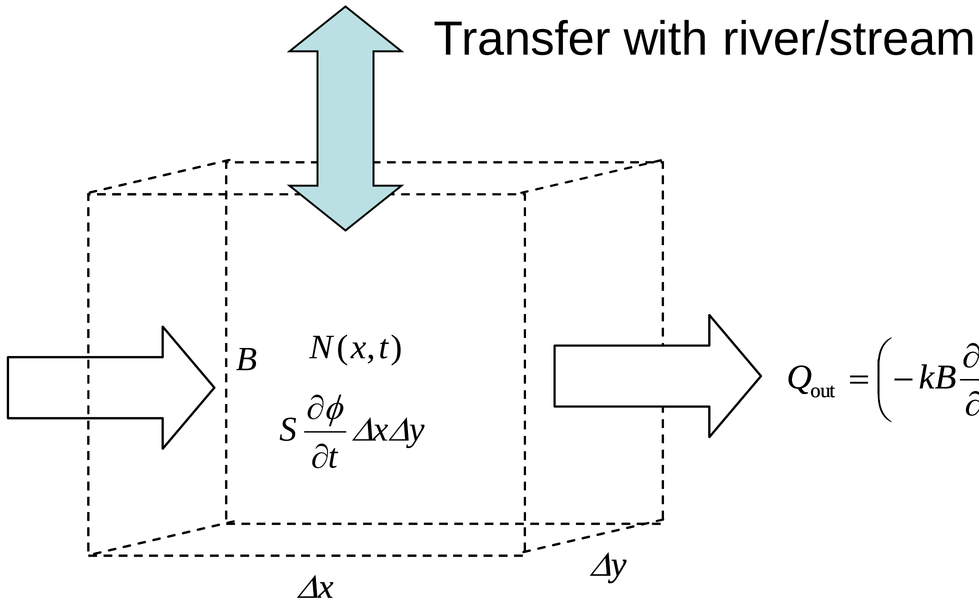
Hyporheic Flow



Hyporehic Flow

$$S\frac{\partial \phi}{\partial t} = \frac{\partial}{\partial x} kB \frac{\partial \phi}{\partial x} + \frac{k'}{b'}\left(\phi_{\circ} - \phi\right)$$

$$Q_{\text{in}} = -kB\frac{\partial \phi}{\partial x}\Delta y$$



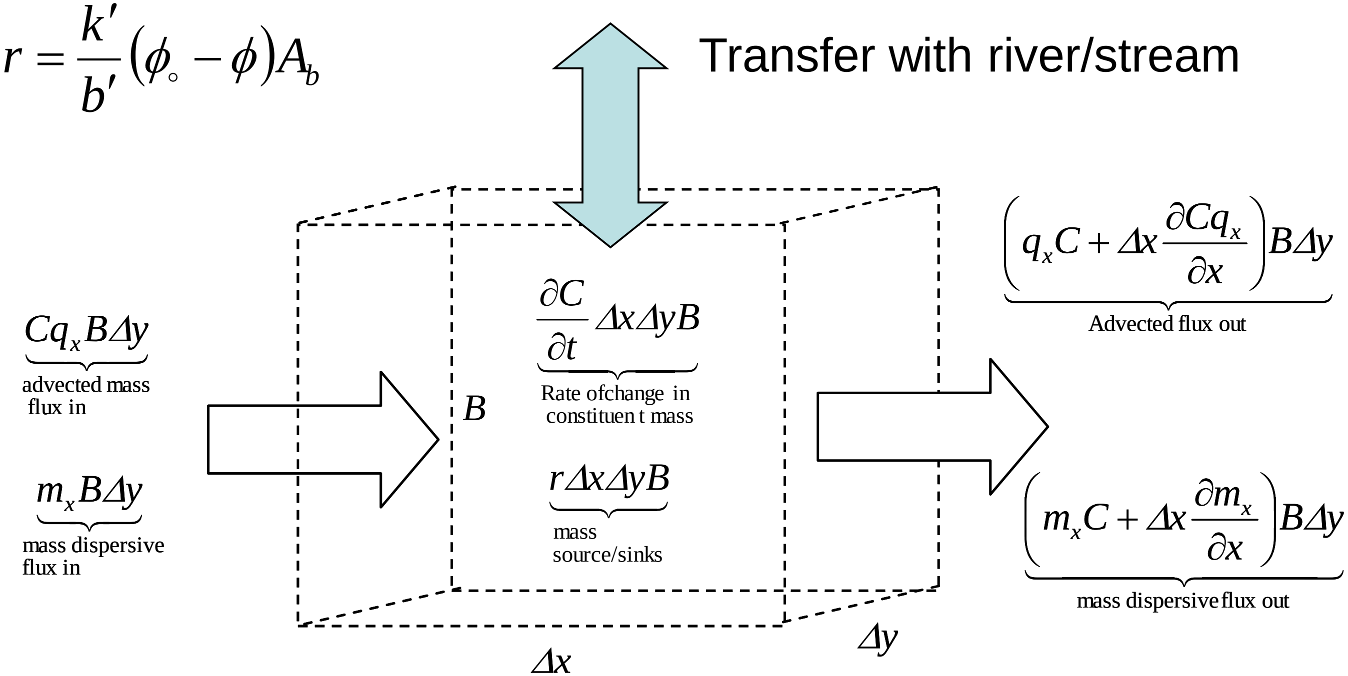
$$Q_{\text{out}} = \left(-kB\frac{\partial \phi}{\partial x} - \Delta x\frac{\partial}{\partial x} kB\frac{\partial \phi}{\partial x}\right)\Delta y$$

Groundwater horizontal movement

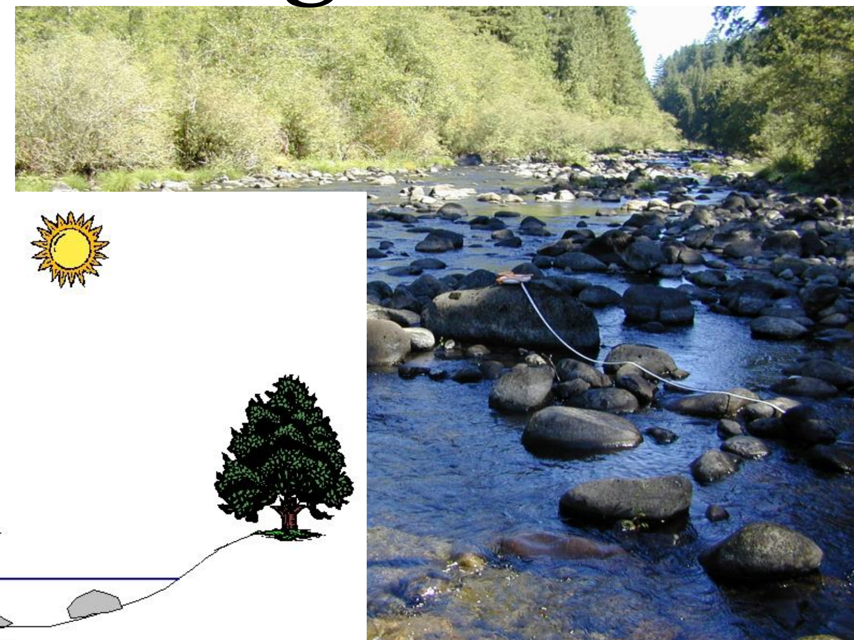
Hyporehic Flow

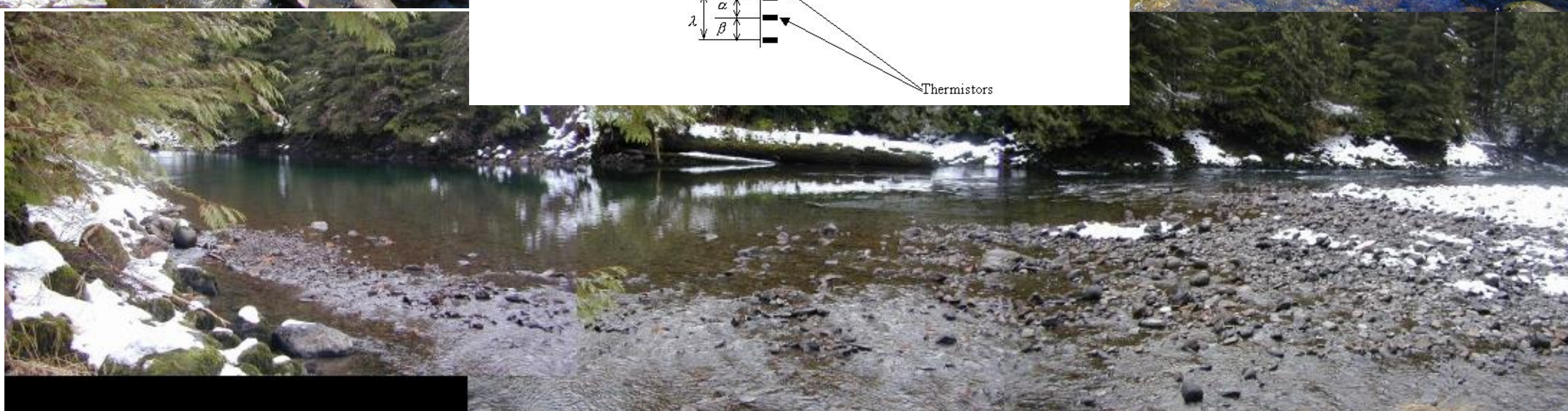
$$\frac{\partial C}{\partial t} + \frac{\partial C q_x}{\partial x} = \frac{\partial}{\partial x} D_x \frac{\partial C}{\partial x} + r$$

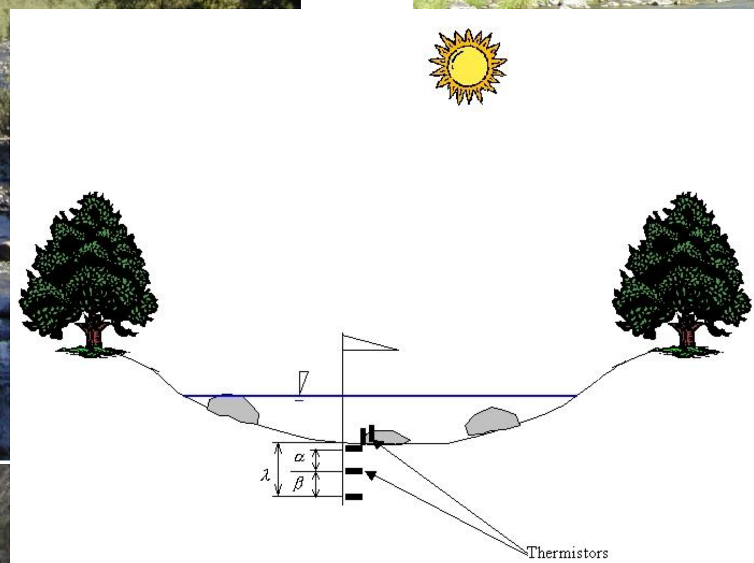
$$r = \frac{k'}{b'}(\phi_\circ - \phi)A_b$$



Channel Bottom Heating



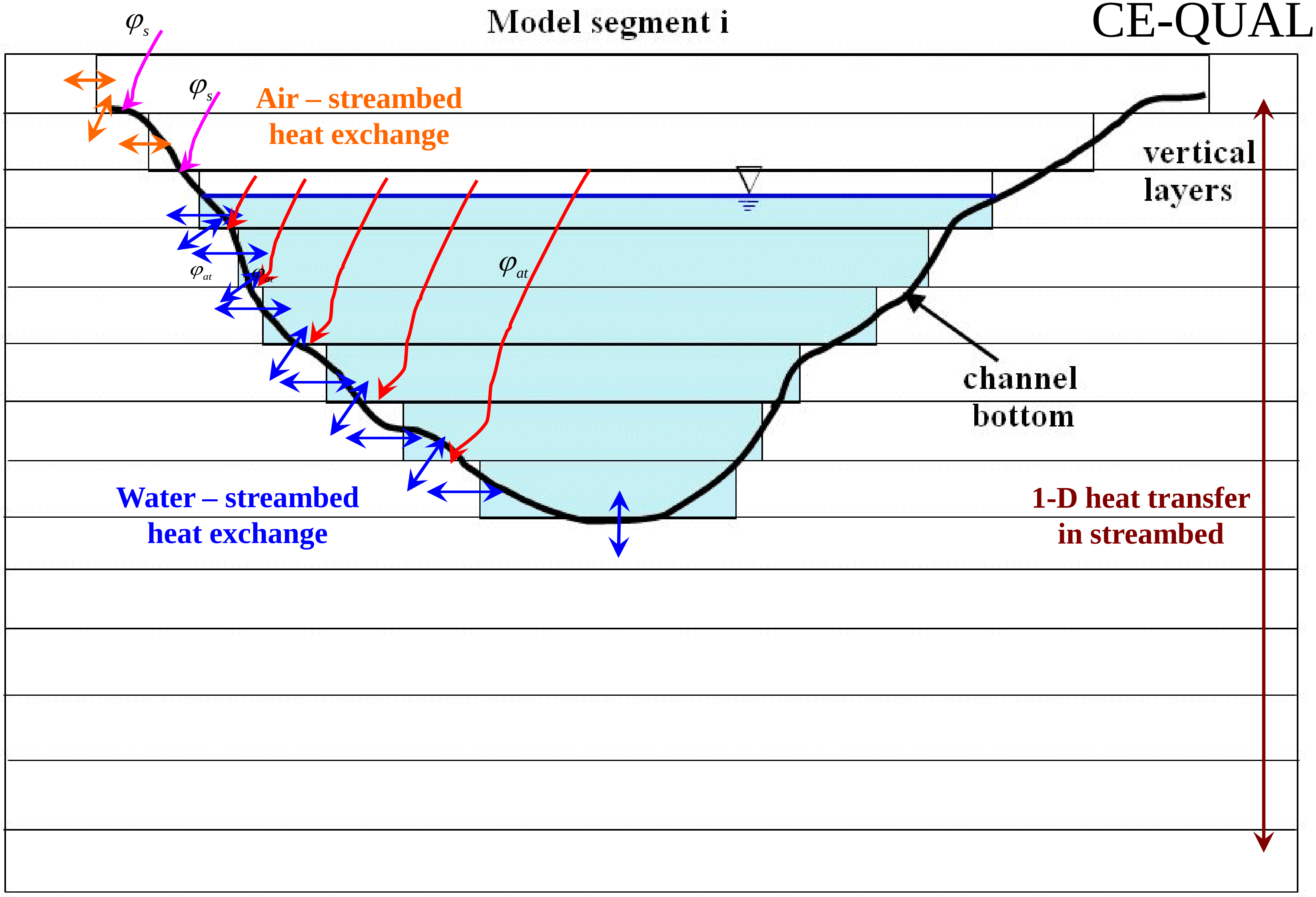




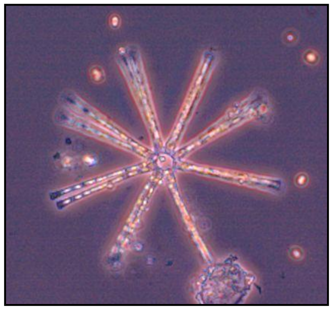
φ_{at}

Streambed Model

Implementation in CE-QUAL-W2



Bioenergetics Modeling



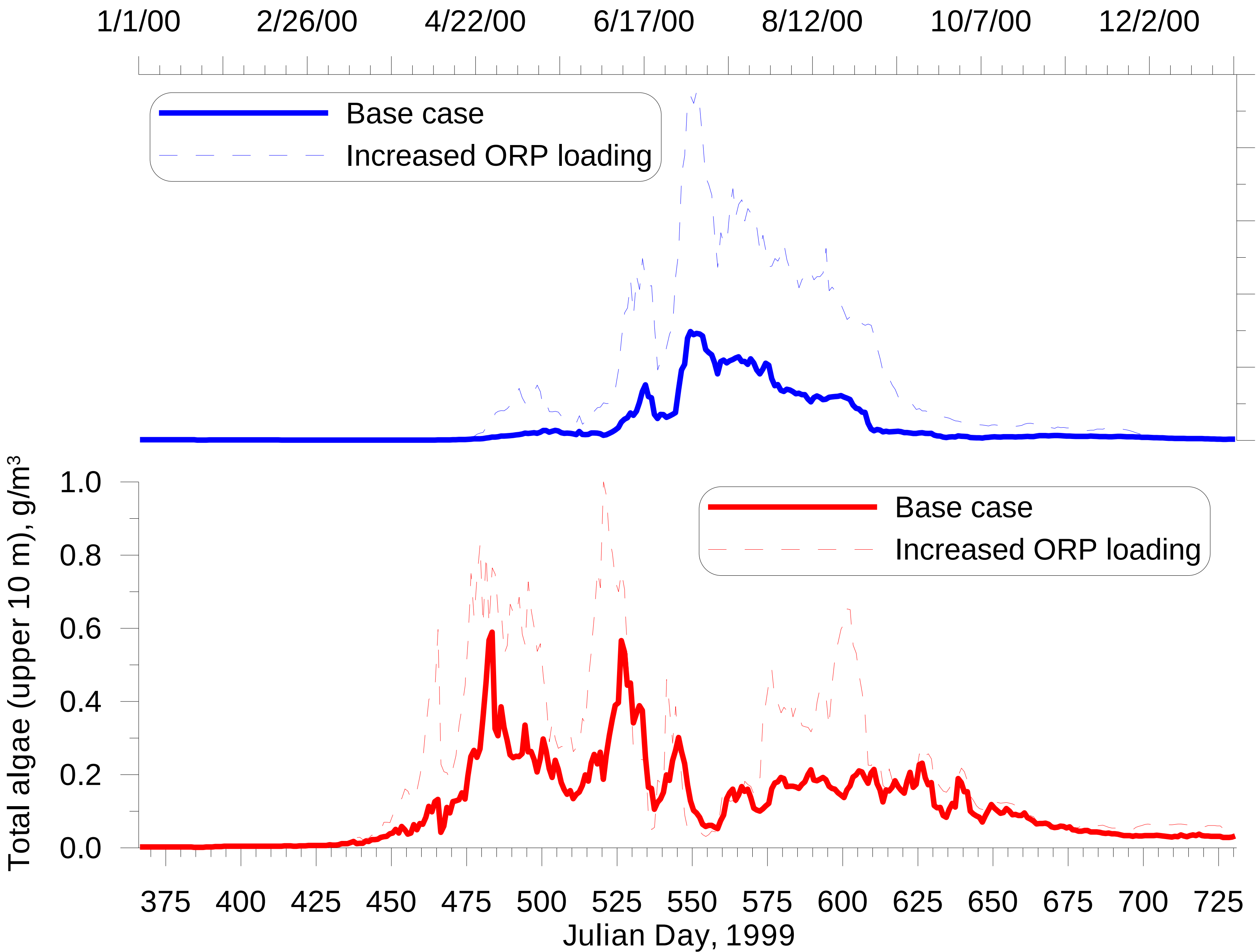
CE-QUAL-W2 Model

Zooplankton feeding rates, organic matter excretion

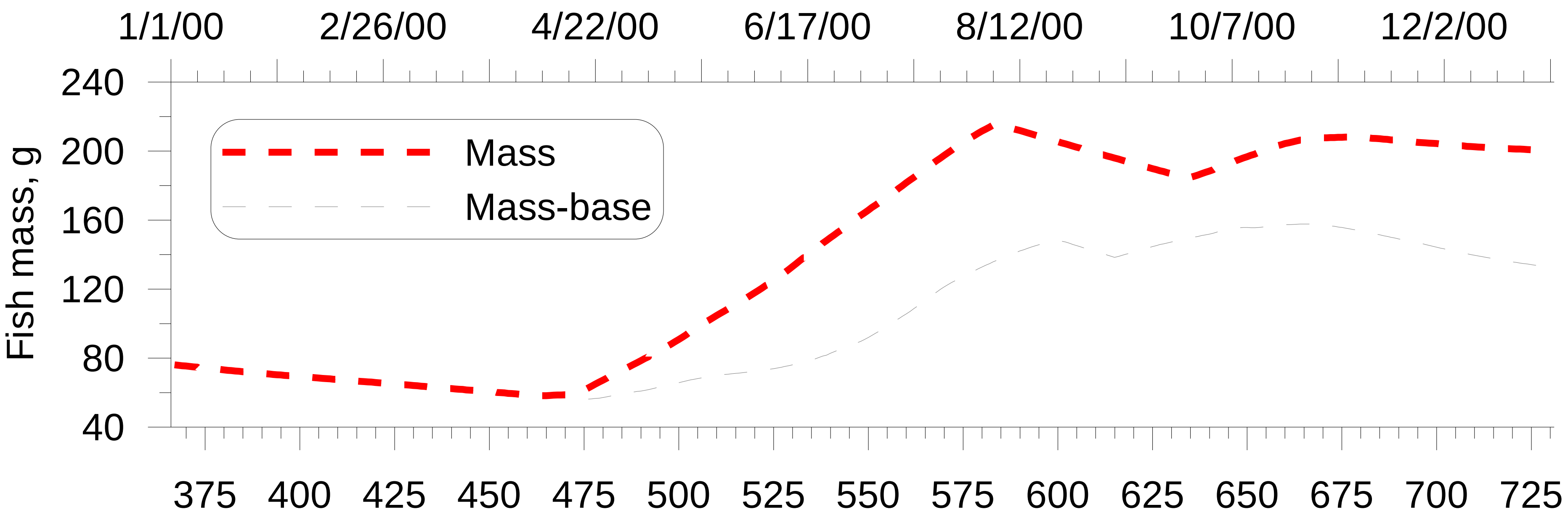
Temperature, zooplankton densities/species, and light as a f(location)

$$\overbrace{G}^{\text{growth}} = \overbrace{C}^{\text{consumption}} - \overbrace{(F + U)}^{\text{waste}} - \overbrace{(R \cdot ACTIVITY + S)}^{\text{metabolism}}$$

Impact of increased nutrient loadings



Increased P loading: effect on Fish mass – 50% increase!



Current Directions: Fish-Particle Bioenergetics Transport Model

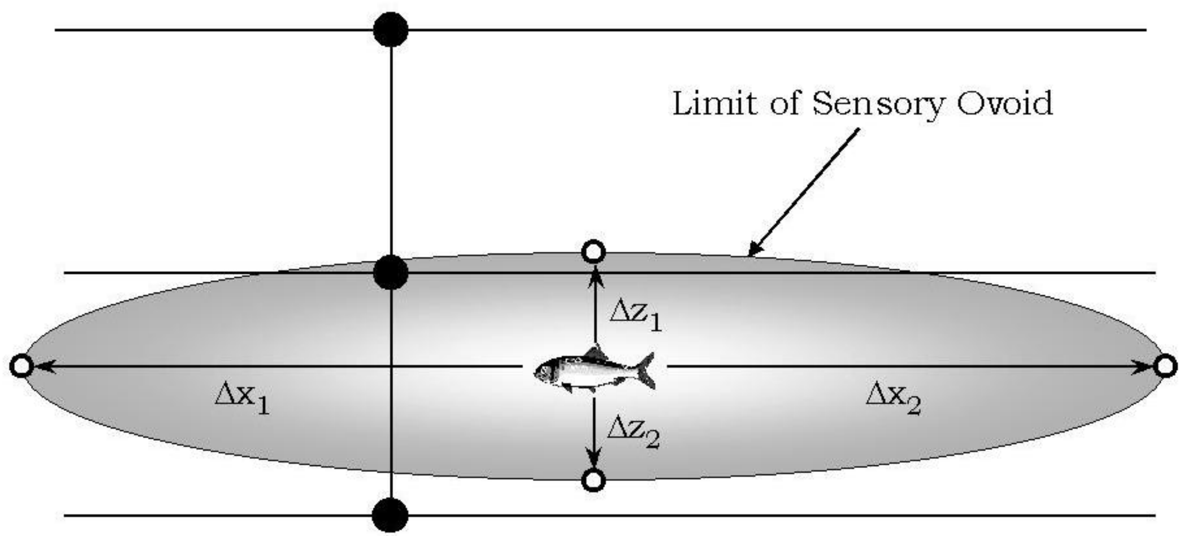
Passive- Andy

Random Transport

Random+Passive

Fish behavior:Velocity

Volitional + Passive movement



Nesler and Goodwin

Sediment Diagenesis Model

Flux of POM

Fluxes of O_2, H_2S, CH_4, NH_4, NO_3, PO_4, Si

$CH_4 \rightarrow CO_2$
$NH_4 \rightarrow NO_3$
Organic matter $\rightarrow CO_2 + NH_4 + PO_4$
$H_2S \rightarrow SO_4$
$NO_3 \rightarrow N_2$

Aerobic layer 1 mm

Diffusion and gas release

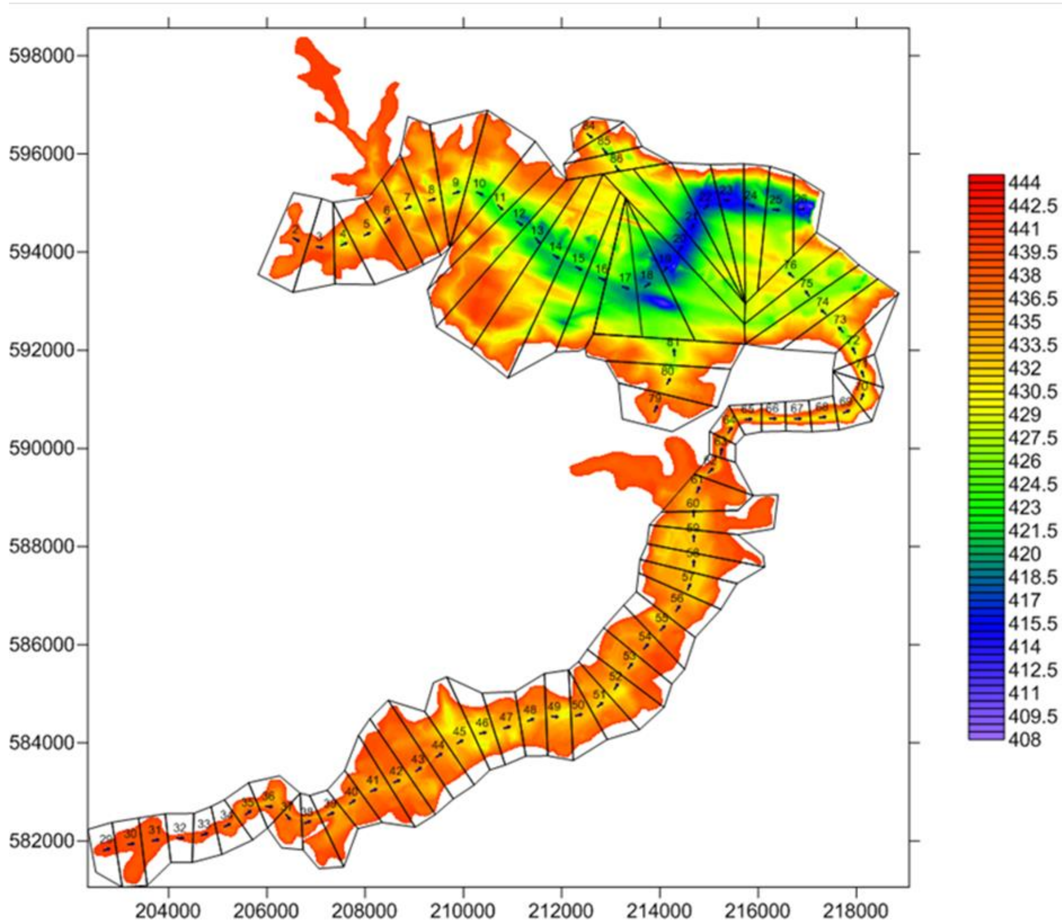
Organic matter $\rightarrow CH_4 + NH_4 + H_2S + PO_4 + Si$
$NO_3 \rightarrow N_2$
Dissolved N_2, CH_4, NH_4, H_2S, $CO_2 \rightarrow$ Gaseous CH_4, NH_4, H_2S, CO_2

Burial

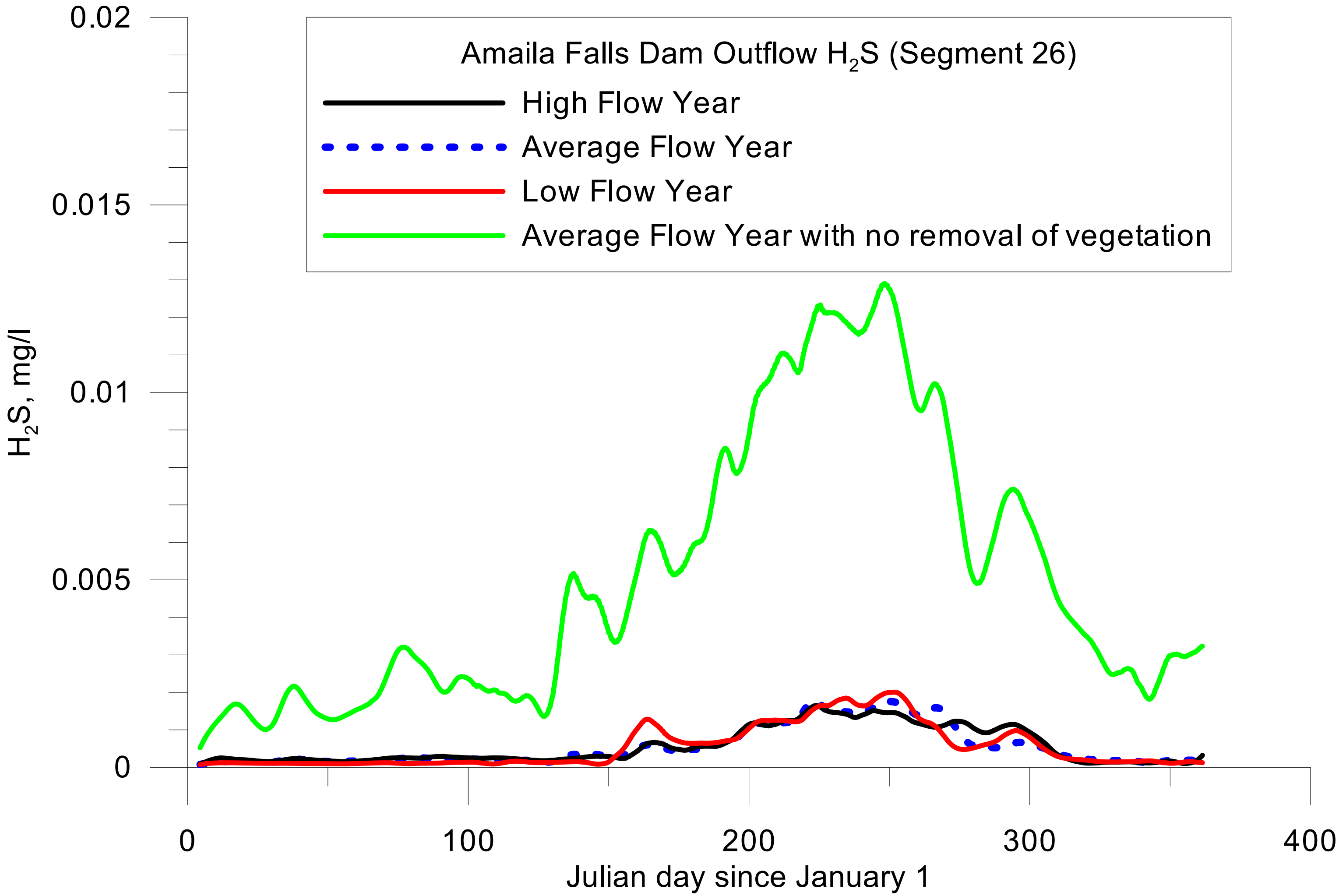
Anaerobic layer 10 cm

Guyana Hydroelectric Project

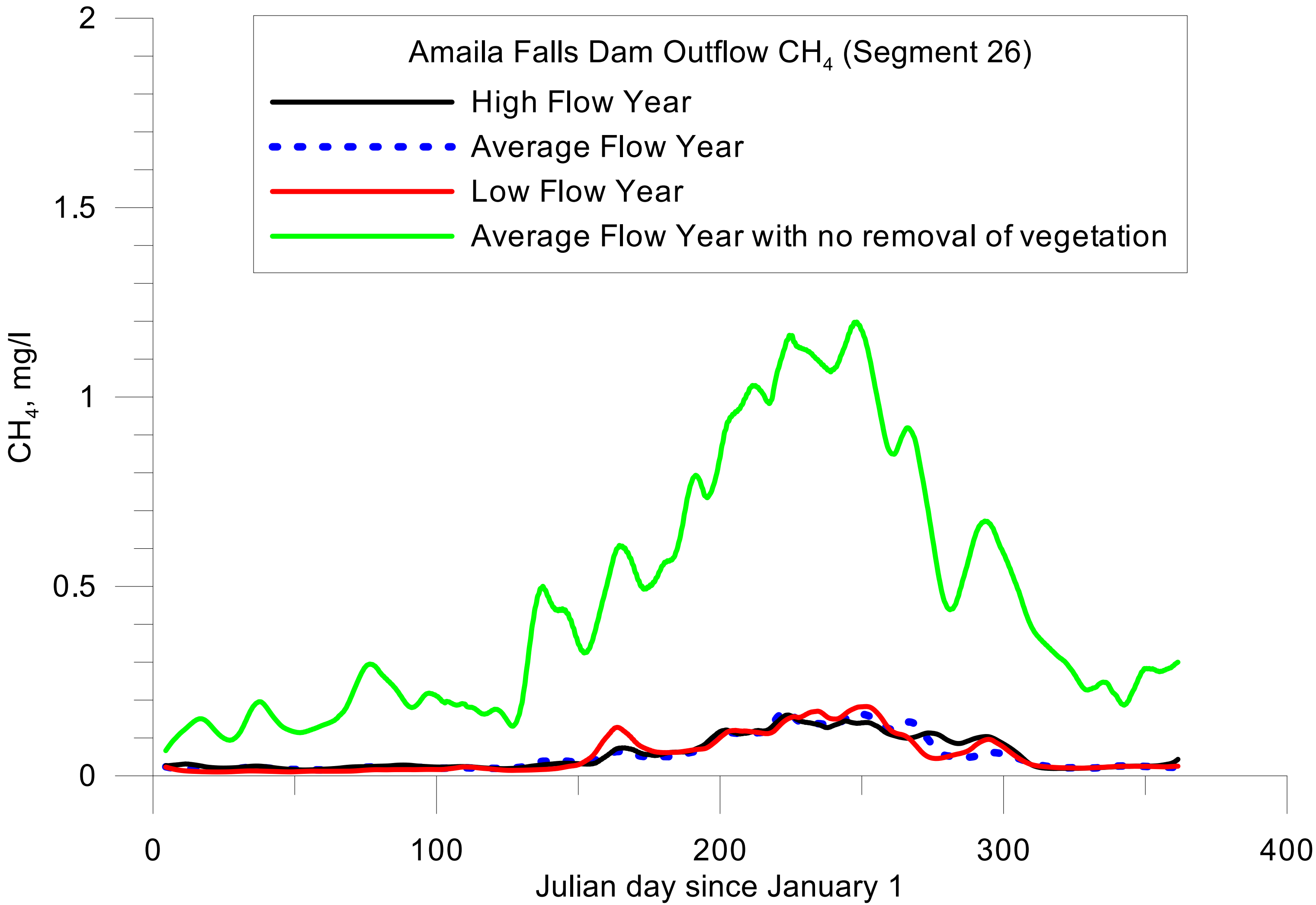
- Max. Surface Area – 23.3 km^2
- Model Segments 439 m to 635 m long
- Vertical Layer Thickness – 1 m



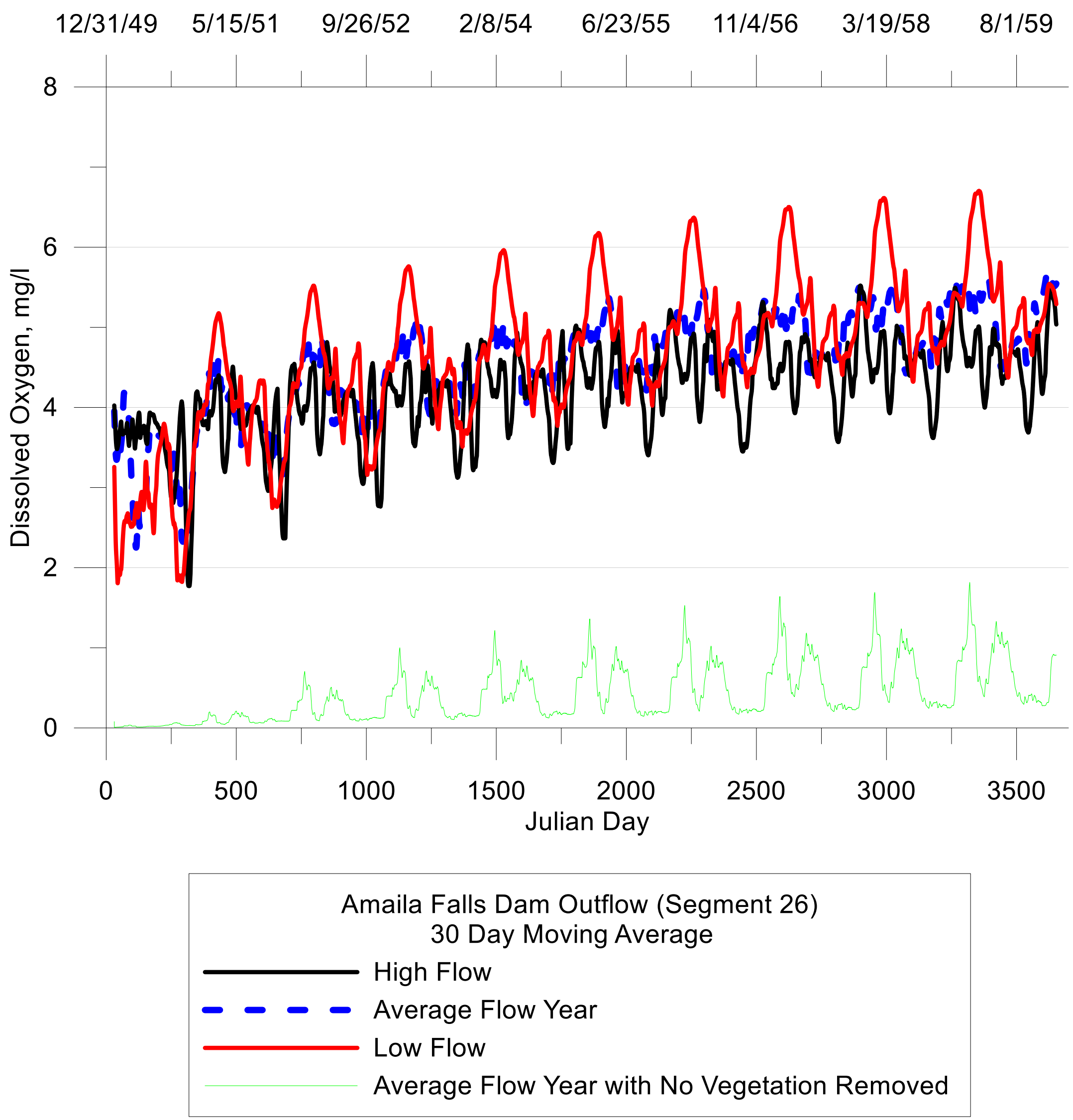
Dam Outflow of Hydrogen Sulfide



Dam Outflow of Methane



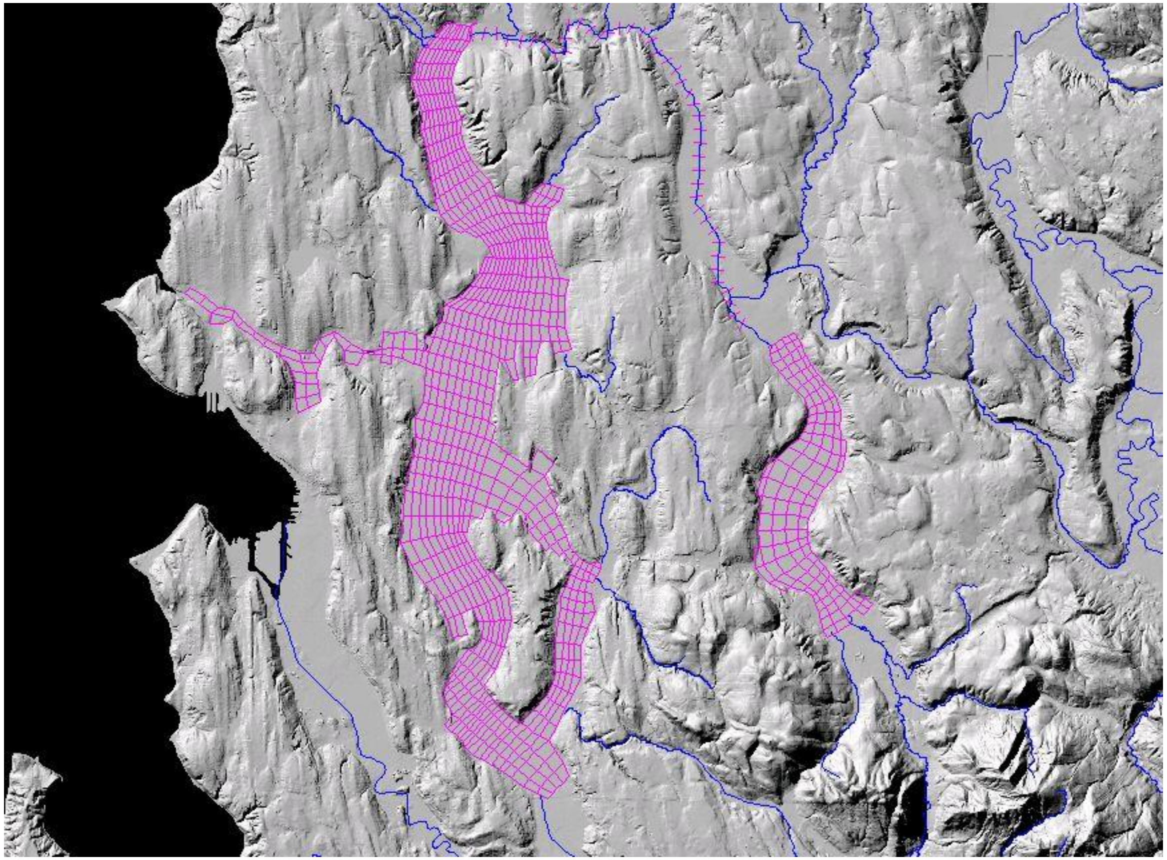
Dissolved Oxygen in Dam Outflow



Summary

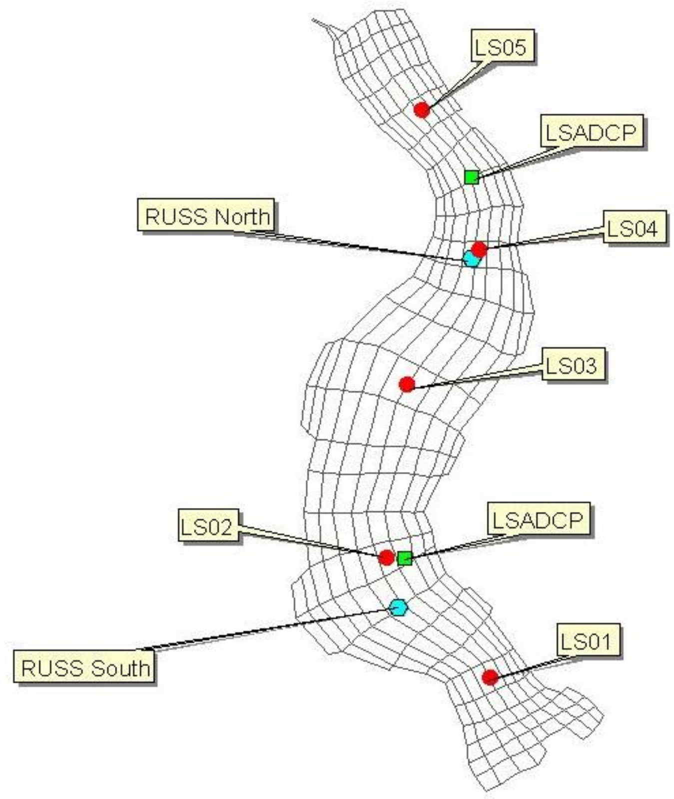
- CE-QUAL-W2 widely used 2D hydrodynamic and water quality model – open source
- New updates coming: sediment diagenesis model, fish bioenergetics and volitional movement, non-conservative alkalinity, …

3D vs 2D?

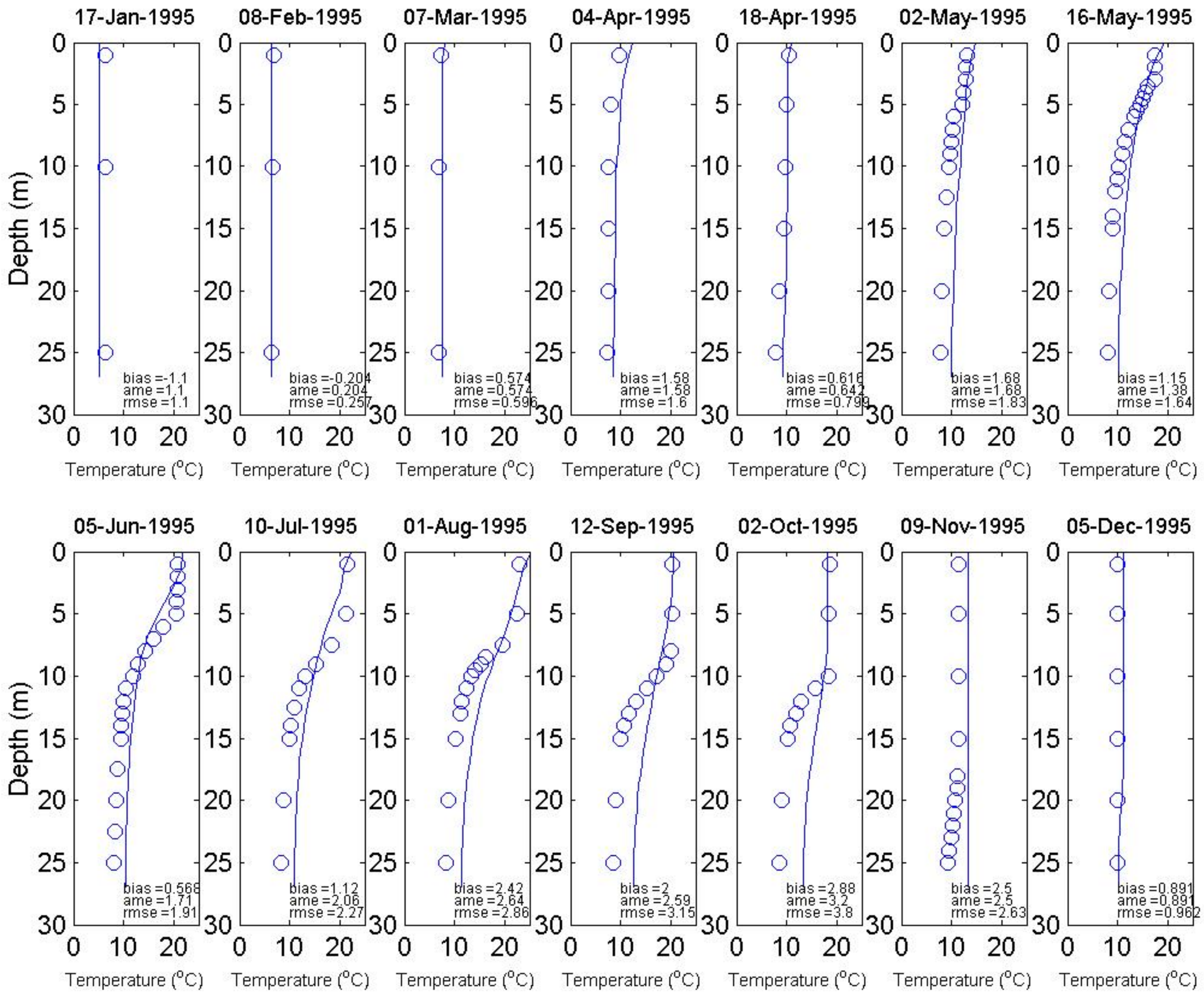


Example from Curtis DeGasperi,
King County

Sammamish Lake, Washington

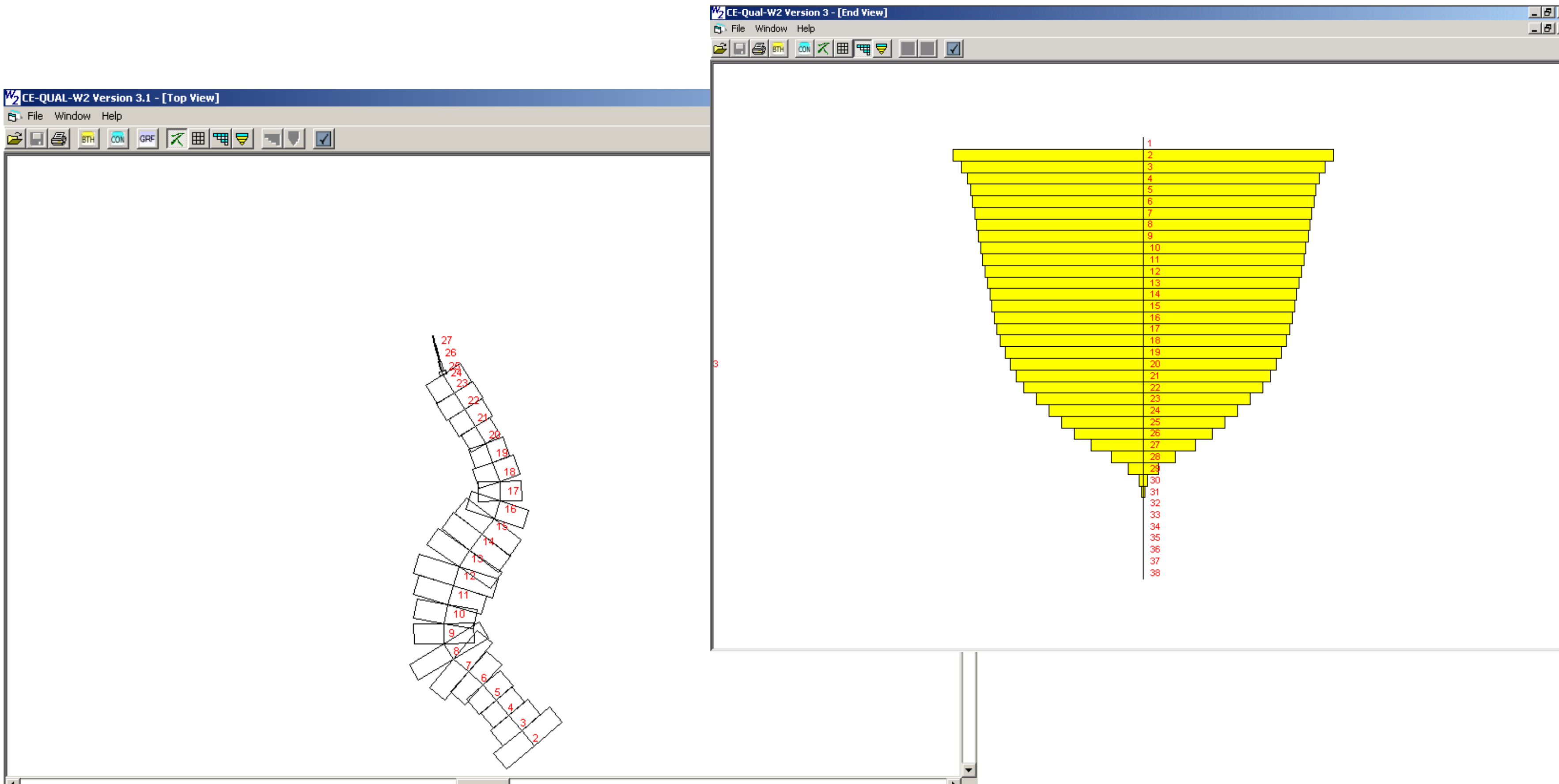


CH3D Model results

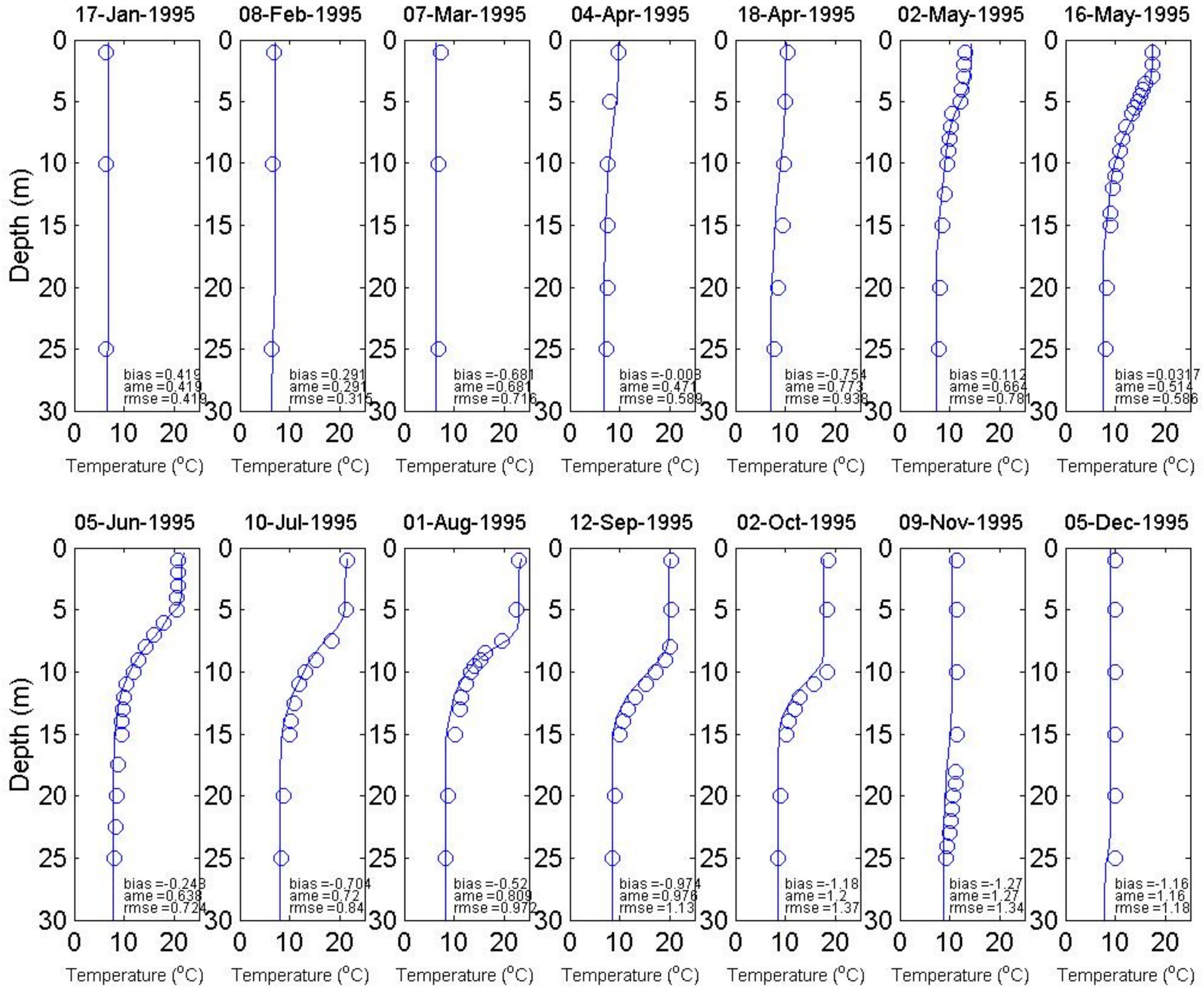


CE-QUAL-W2

Laterally Averaged 2-D water quality model



CE-QUAL-W2 Results – only 2-D



Model Run Time Differences

8 year simulation on a 3GHz Xenon (I know its old) from Curtis DeGasperi

CH3D: 16:40 hours

CE-QUAL-W2: 1:10 hours

Note in the end – both models had similar model vs data error.